



The Tropical Composite Cyclones: the integrated effect of hurricanes on the ocean-atmosphere coupled system

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- 1) INGV – Istituto Nazionale di Geofisica e Vulcanologia - Bologna, Italy
- 2) CMCC - Euro Mediterranean Center for Climate Change - Bologna, Italy

OUTLINE

1. ERA-Interim data set and Tropical Cyclones representation.
2. Tropical Composite Cyclones (TCC) over West North Pacific (WNP) and Atlantic (ATL) Oceans:
A representation of the TCs fingerprint on the mean climate.
3. TCC interplay with the ocean: results from a fully coupled hi-res General Circulation Model.



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Tropical Cyclones representation in ERA-Interim data set

The ERA-INTERIM (*) ECMWF Re-Analyses Data set

Data Assimilation through four-dimensional variational assimilation, 4D-Var, in a ~70 Km numerical weather prediction model (using a spectral grid with triangular truncation of 255 waves and a hybrid vertical coordinate system with 60 levels.).

Fields assimilated:

- Aircraft observations
- Ocean drifter observations
- Wind profiler observations
- Balloon-borne observations
- Dropsonde
- Satellite observations
- Surface observations

Covered period: 1989 – now

Data availability: 6 hourly

The sea-surface-temperature (SST) and sea-ice fields as used in ERA-Interim come from these sources:

- NOAA/NCEP 2D-Var weekly dataset (Reynolds et al., 2002) ;
- Jan 1989-Jun 2001 NOAA/NCEP OISST V2 weekly dataset (Fiorino, 2004) ;
- Jul 2001-Dec 2001 NOAA/-NCEP Real-Time Global (RTG) daily dataset (Gemmill, 2007) ;
- Jan 2002-Jan 2009 Met Office Op. SST and Sea Ice Analysis (OSTIA) daily dataset (Stark et al., 2007) ;

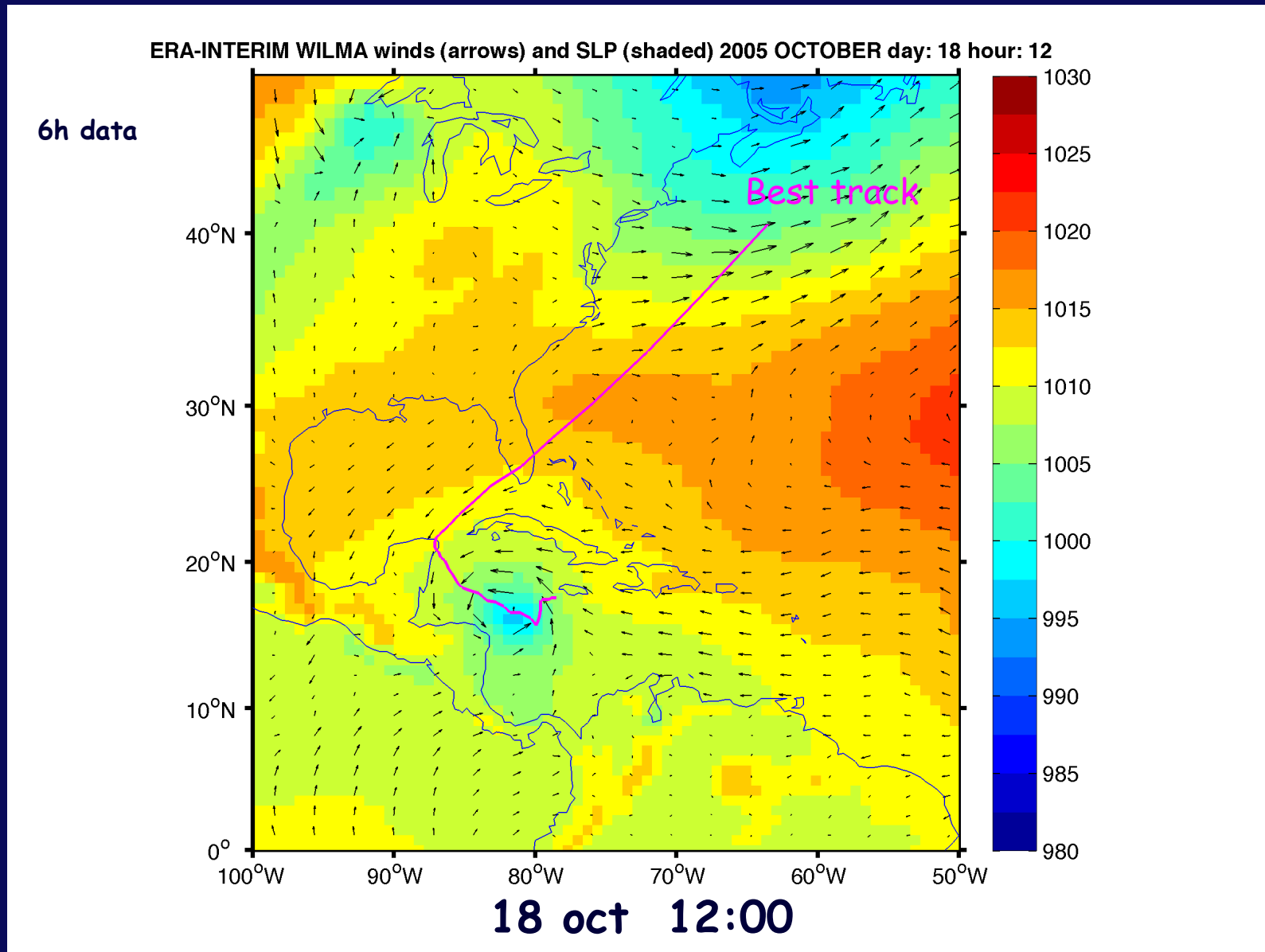


(*) Simmons, A., S. Uppala, D. Dee, and S. Kobayashi, 2007: ERA-Interim: New ECMWF reanalysis products from 1989 onwards. Newsletter 110 - Winter 2006/07, ECMWF, 11pp.



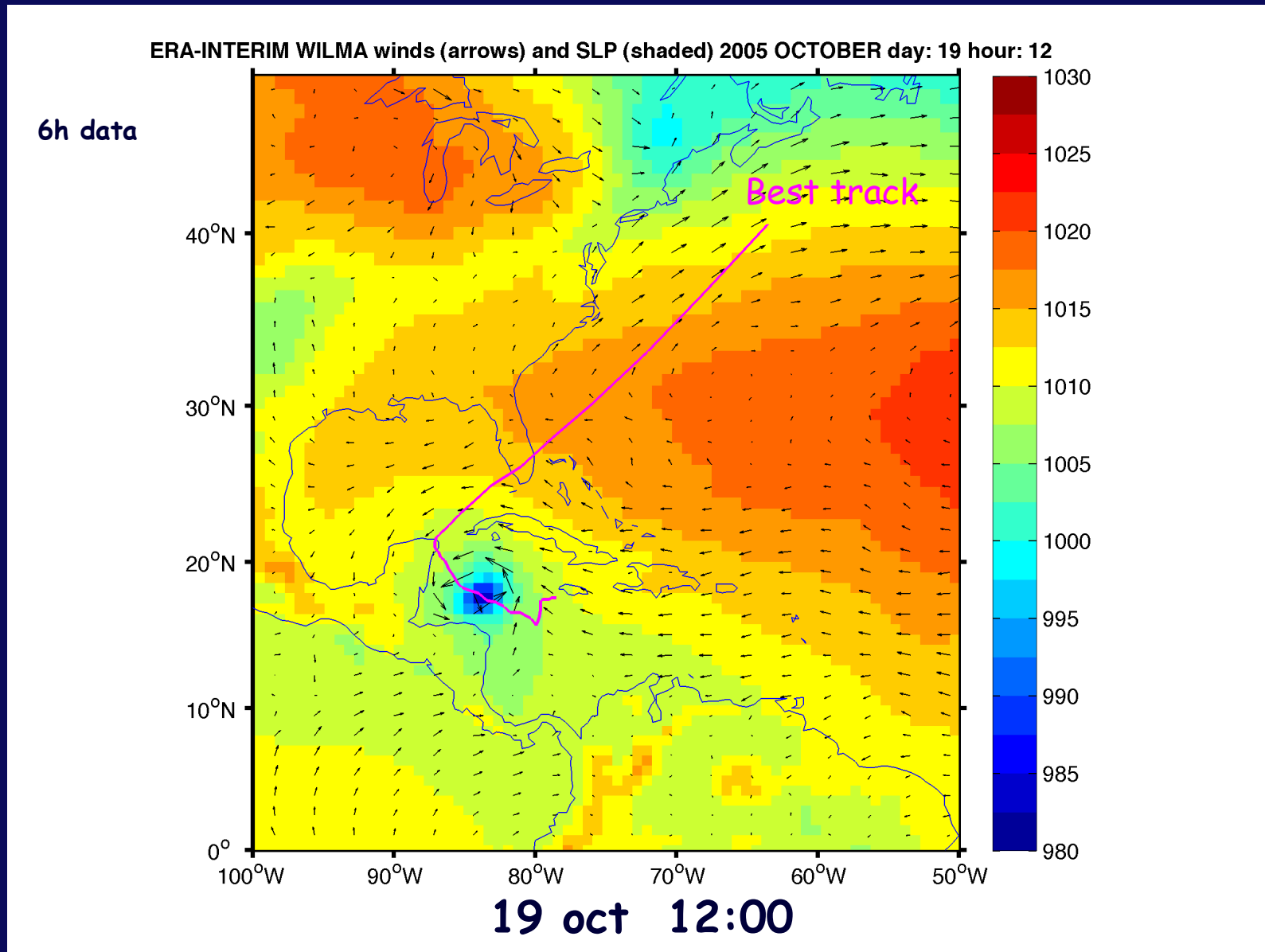
Tropical Cyclones representation in ERA-Interim data set

Hurricane wilma, 18-26 October 2005



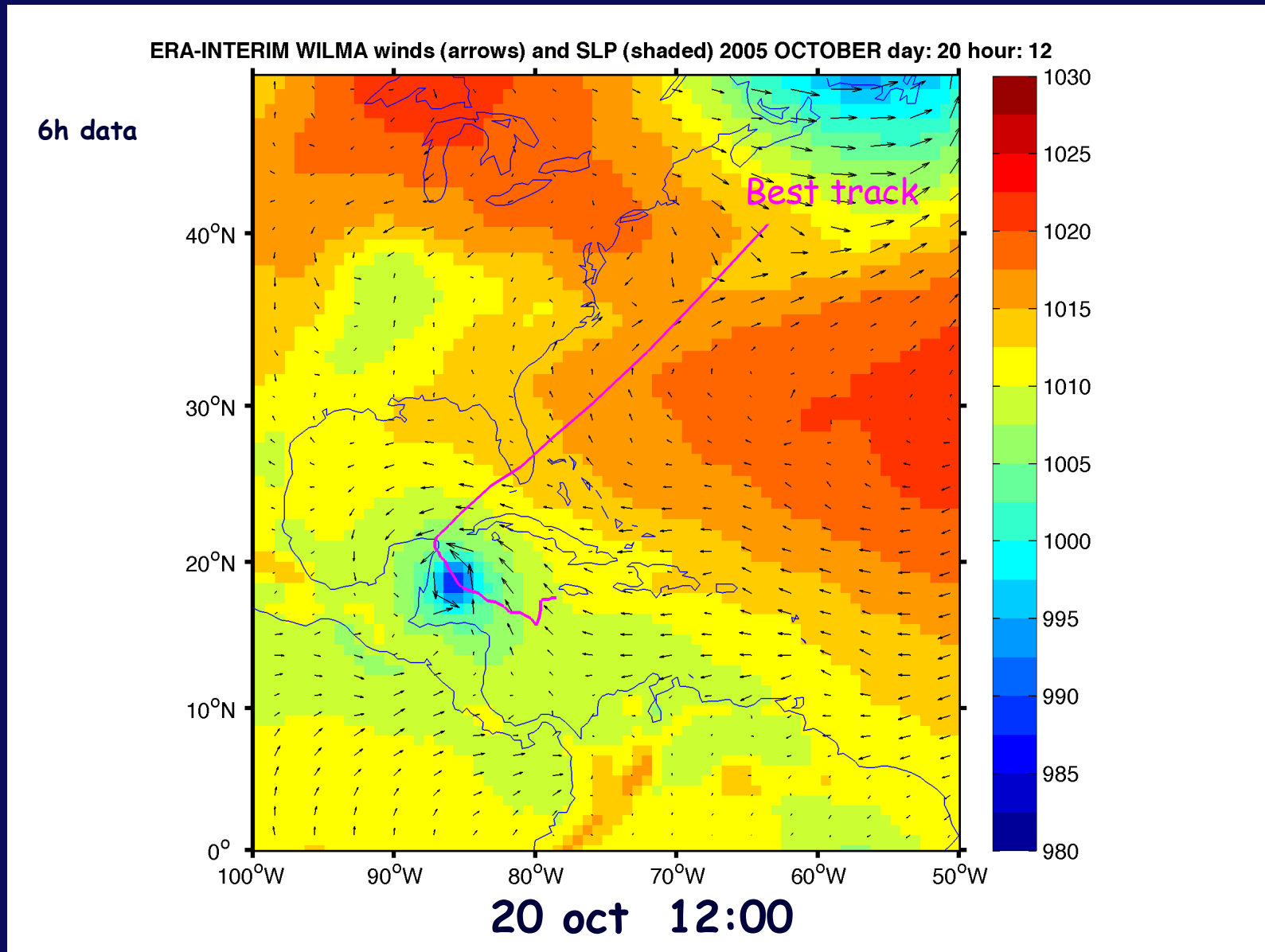
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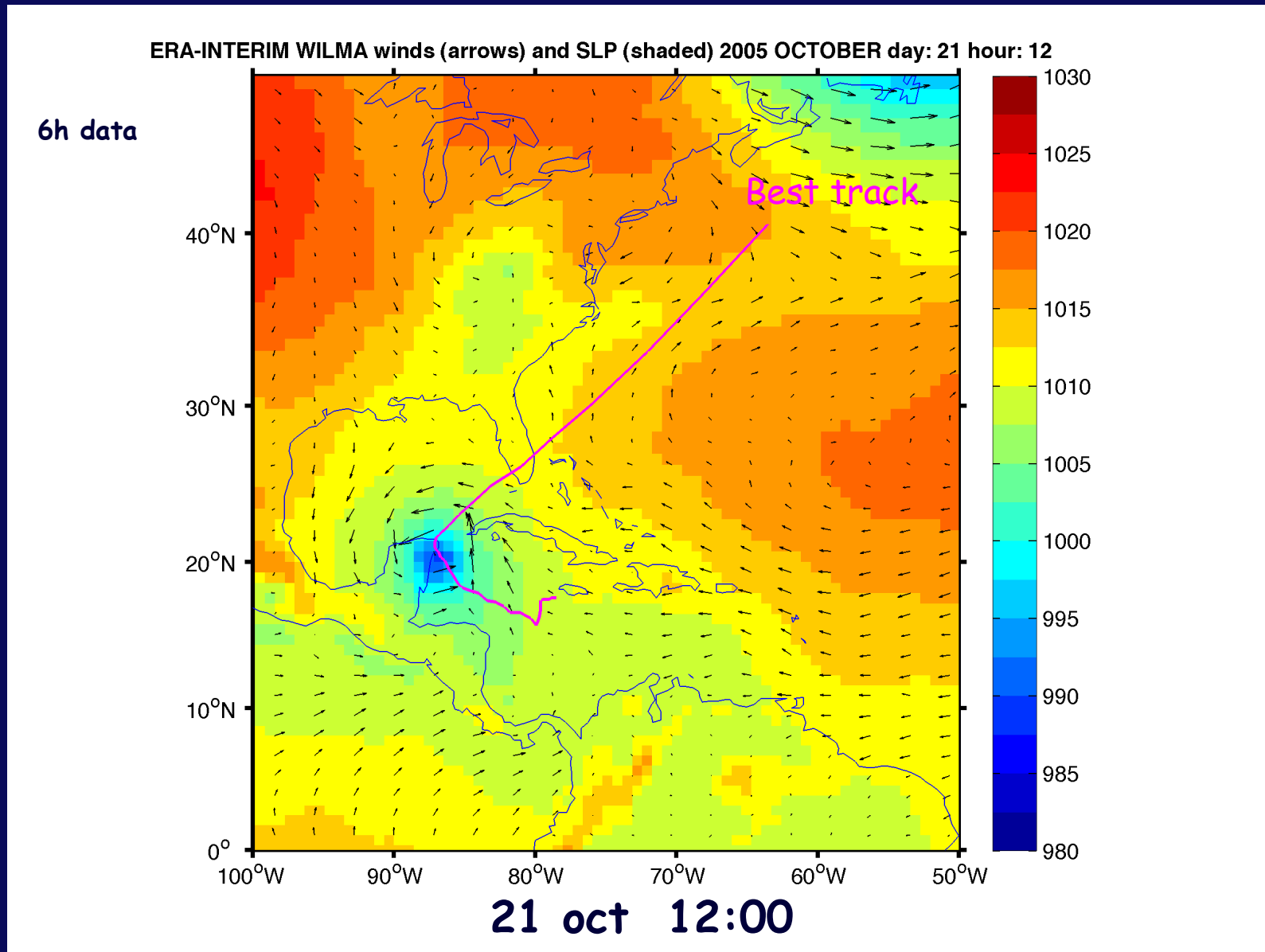
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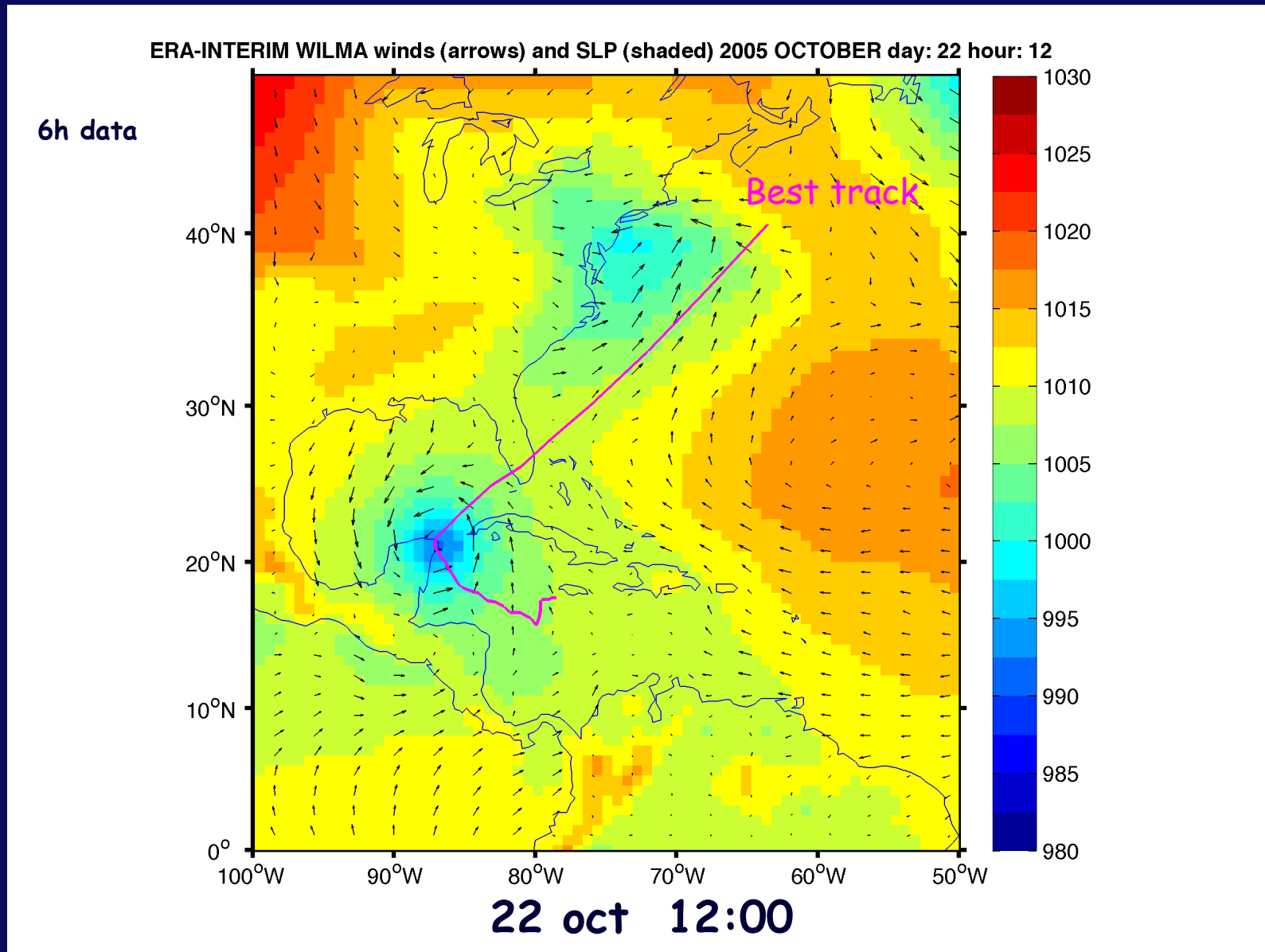
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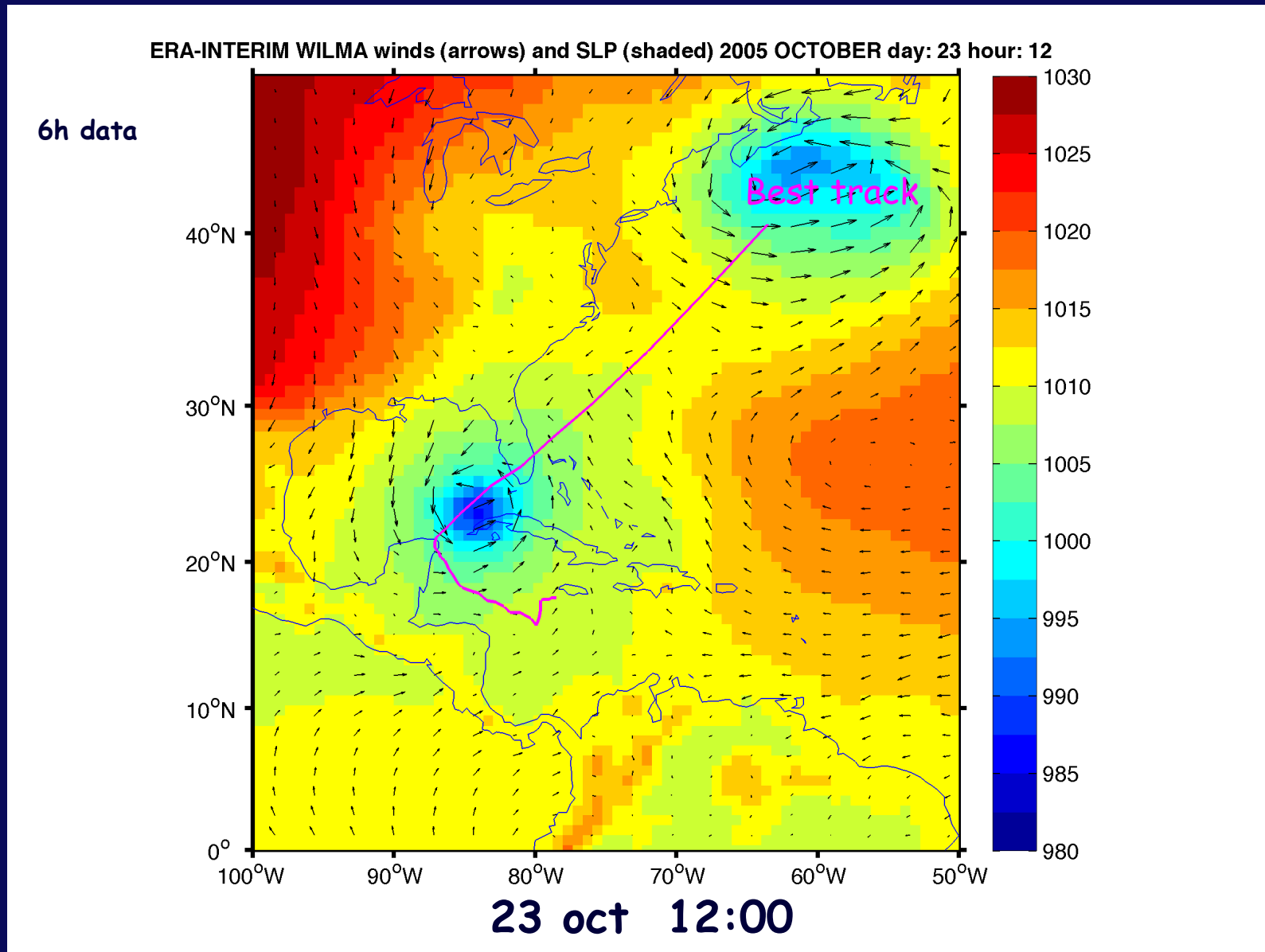
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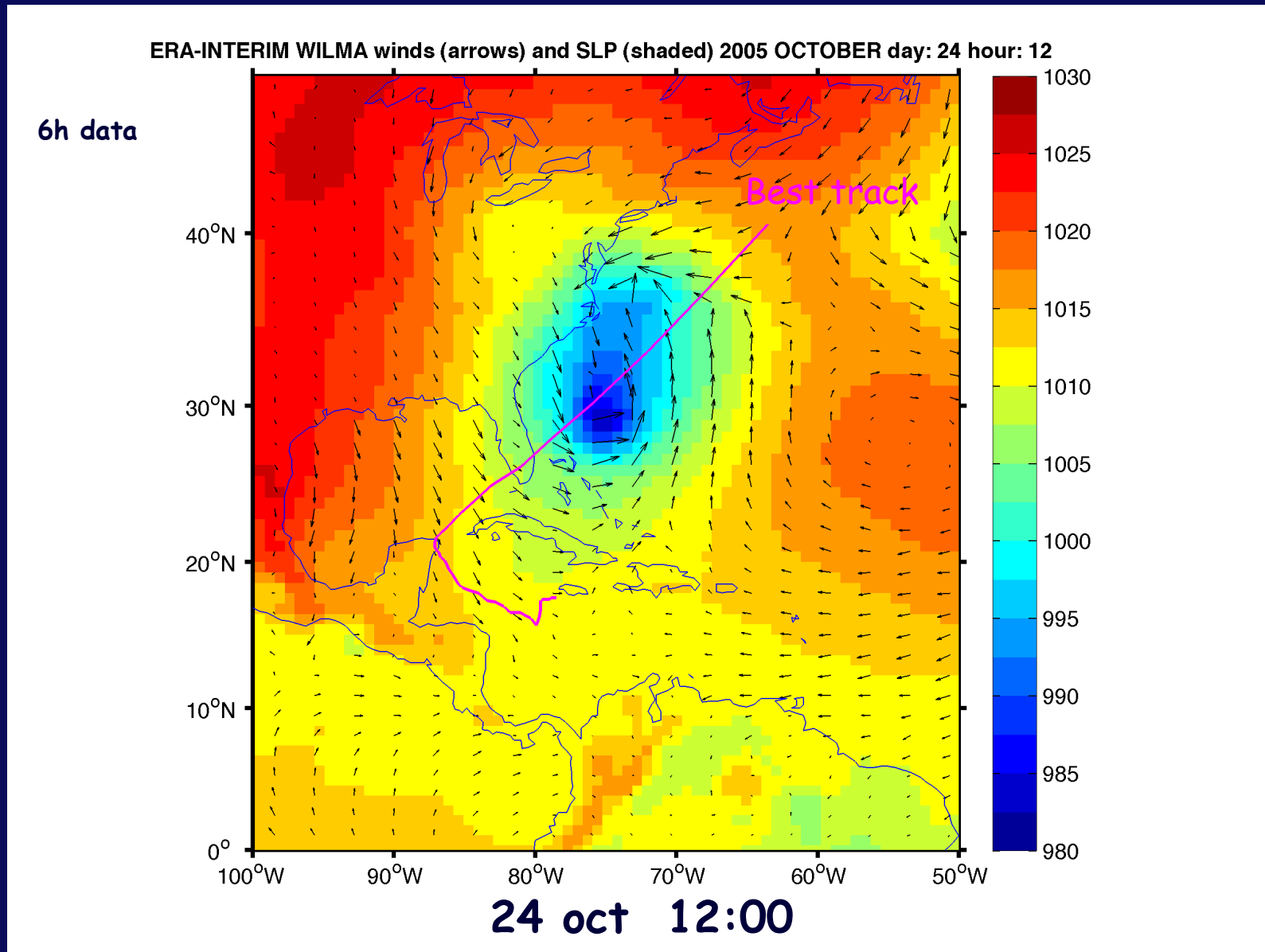
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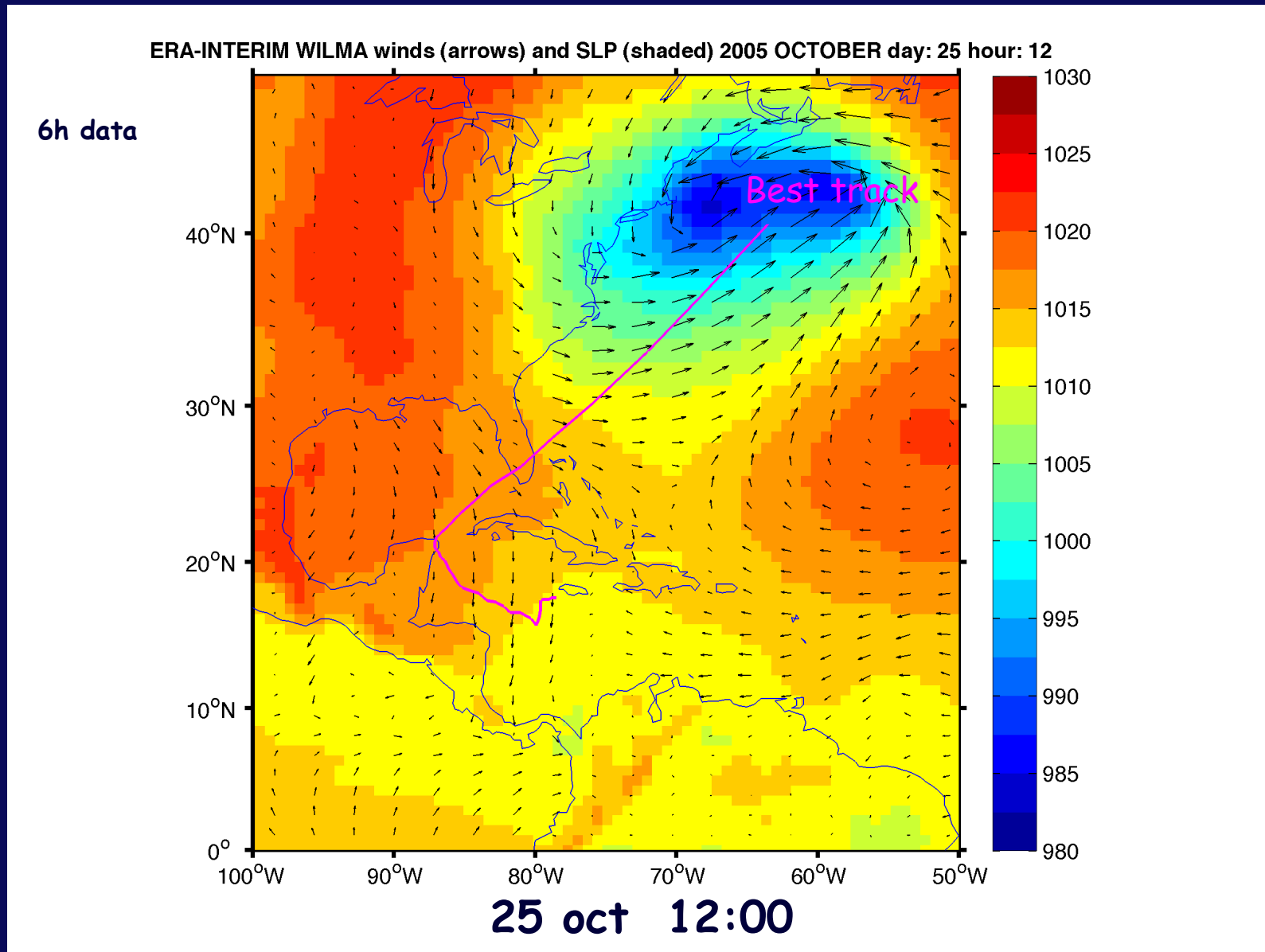
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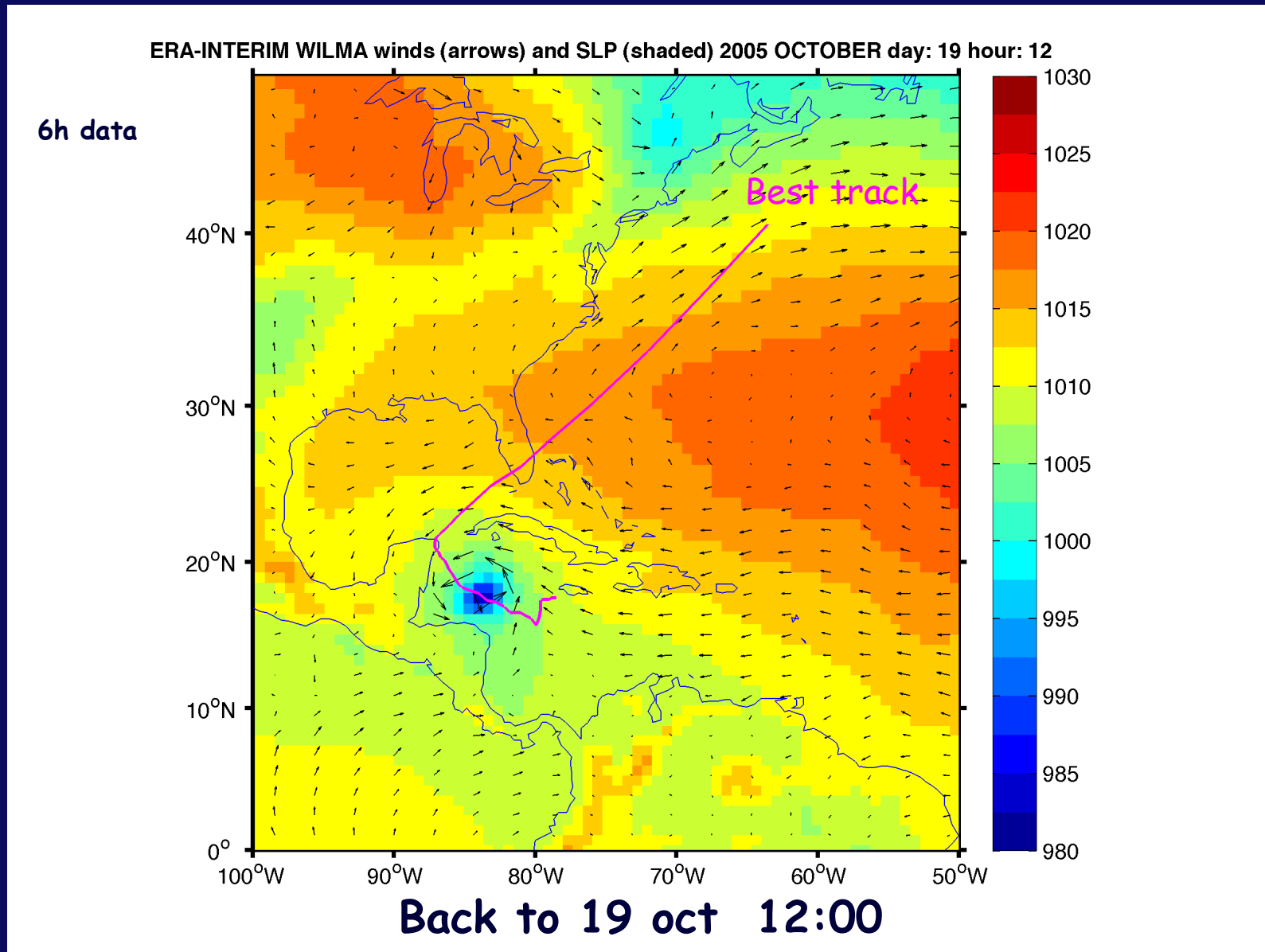
Tropical Cyclones representation in ERA-Interim data set

Hurricane wilma, 18-26 October 2005



Tropical Cyclones representation in ERA-Interim data set

Hurricane wilma, 18-26 October 2005



6h averaged winds (19 oct 06:00-12:00) = 50 m/s (\geq cat3)

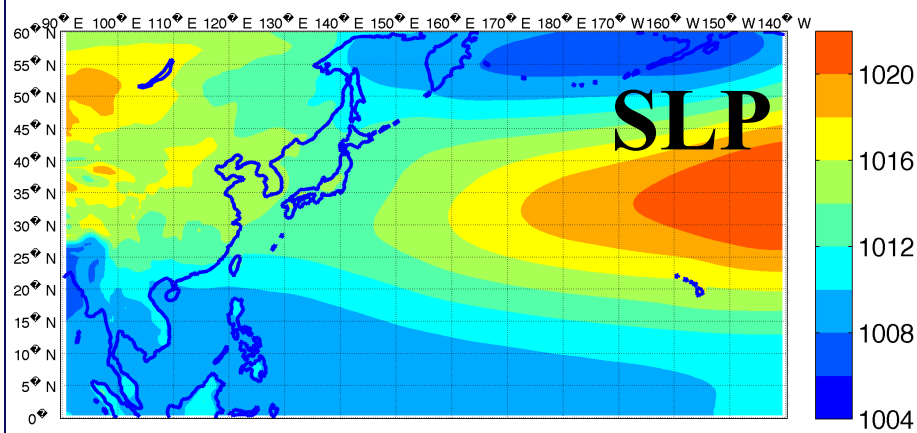


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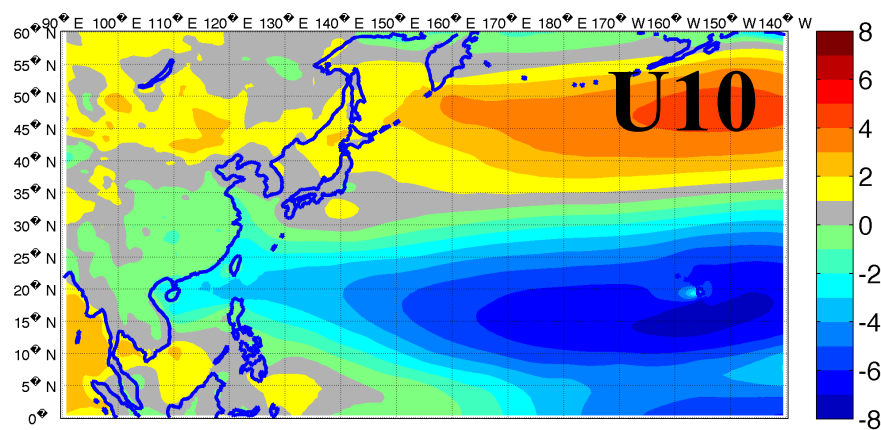
ERA-INTERIM 1989-2009 SLP June-December average [mb]



SLP

1989-2009 June-December
ERA-Interim CLIMATOLOGY

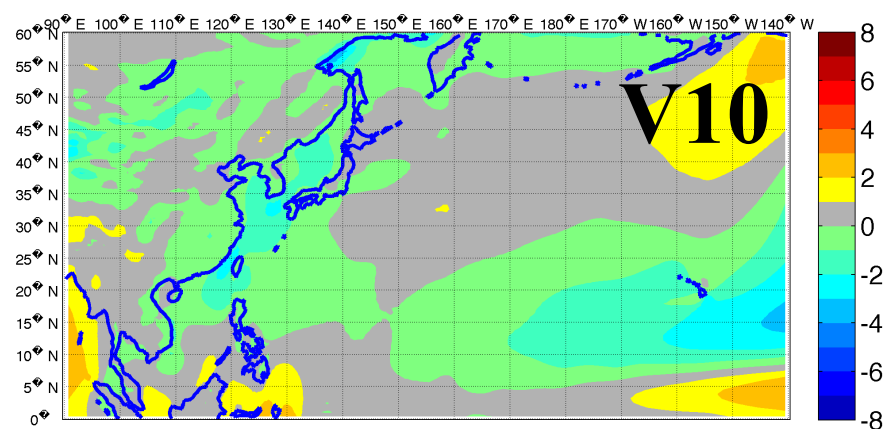
ERA-INTERIM 1989-2009 U June-December average [m/s]



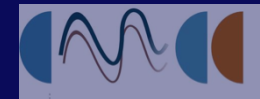
U10

West-North Pacific
(WNP)

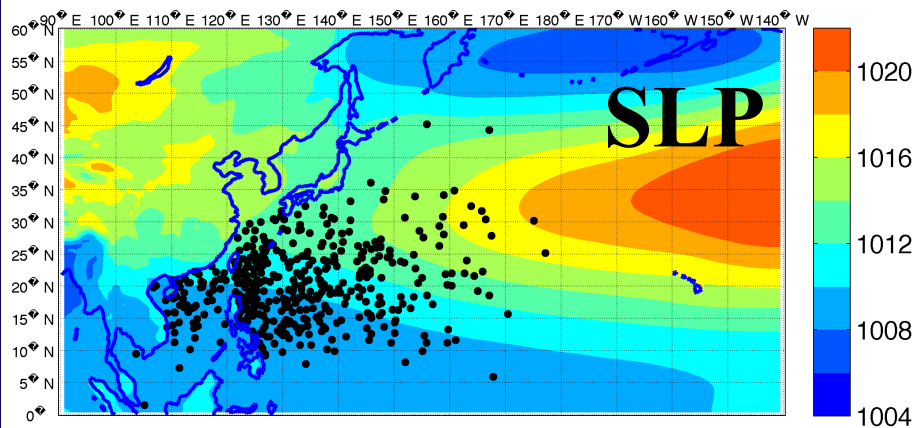
ERA-INTERIM 1989-2009 V June-December average [m/s]



V10



ERA-INTERIM 1989-2009 SLP June-December average [mb]



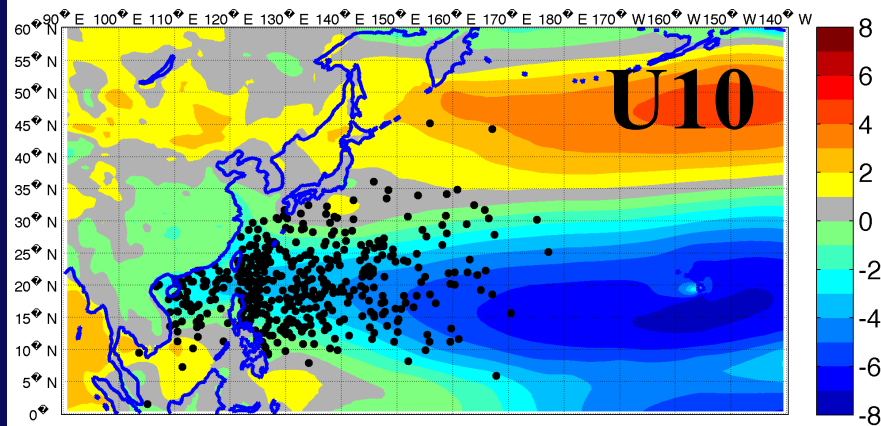
SLP

1989-2009 June-December
ERA-Interim CLIMATOLOGY

+

TYPHOONS max intensity location
(black dots: 308 TY considered
-> 18 Ty/year [Chan & Shi 1996])

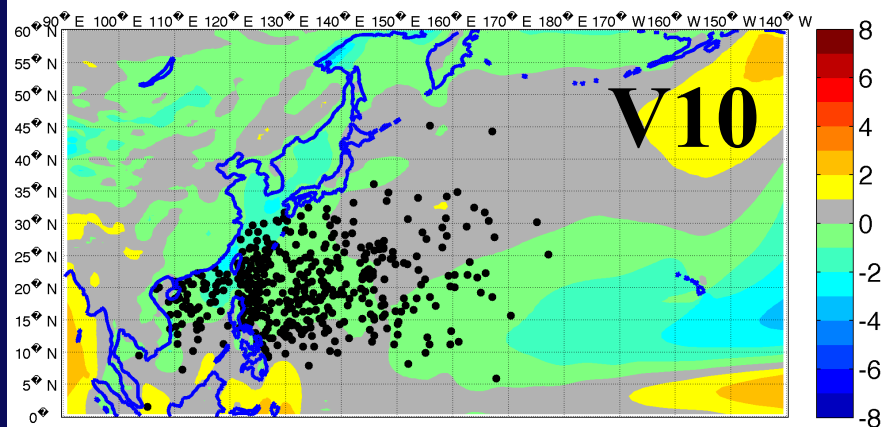
ERA-INTERIM 1989-2009 U June-December average [m/s]



U10

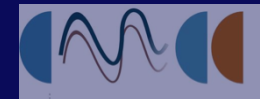
West-North Pacific
(WNP)

ERA-INTERIM 1989-2009 V June-December average [m/s]

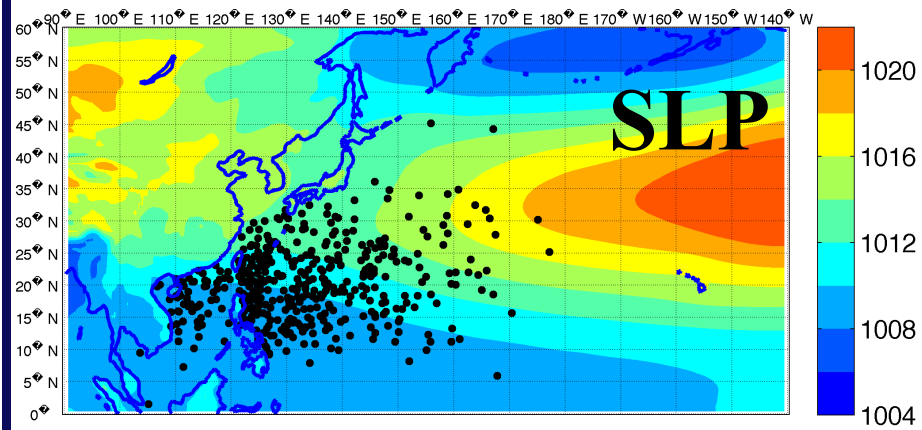


V10

Composite TC induced anomalies
computation on a daily time basis
Ongoing -> next slide

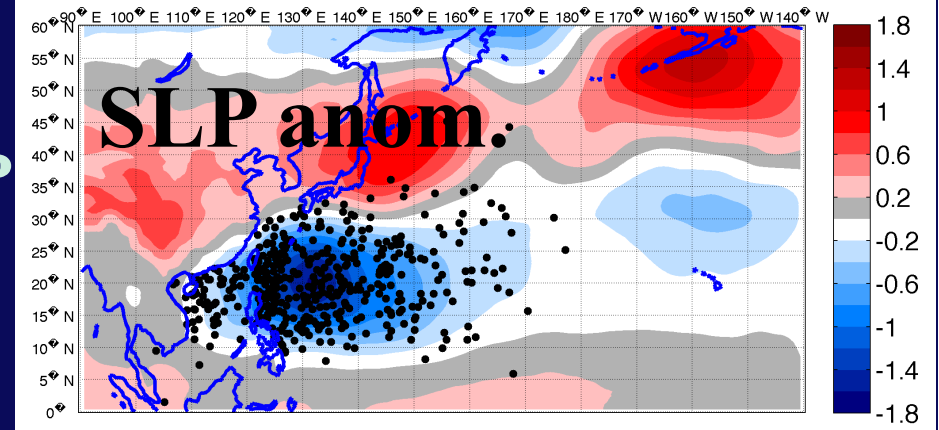


ERA-INTERIM 1989-2009 SLP June-December average [mb]

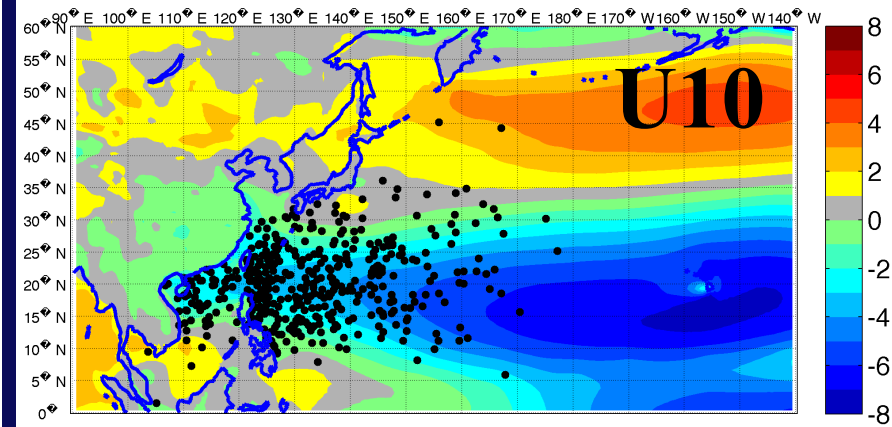


SLP

ERA-INTERIM 1989-2009 SLP -TYPHOON INDUCED ANOMALY- [mb]

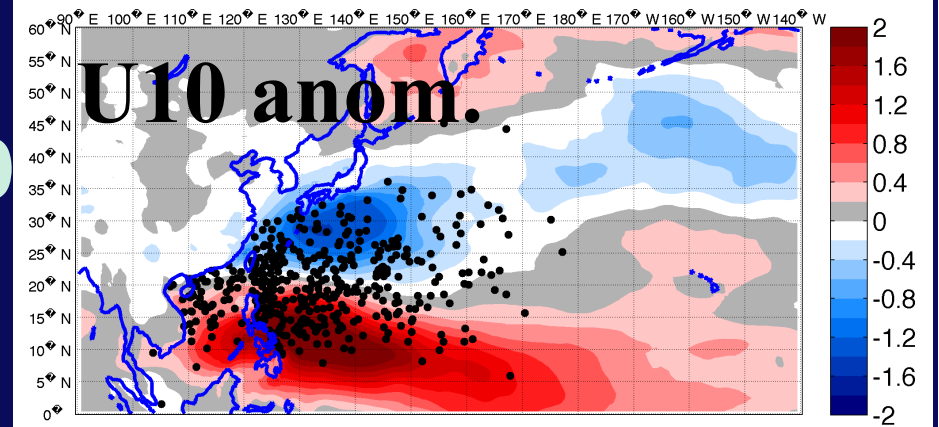


ERA-INTERIM 1989-2009 U June-December average [m/s]

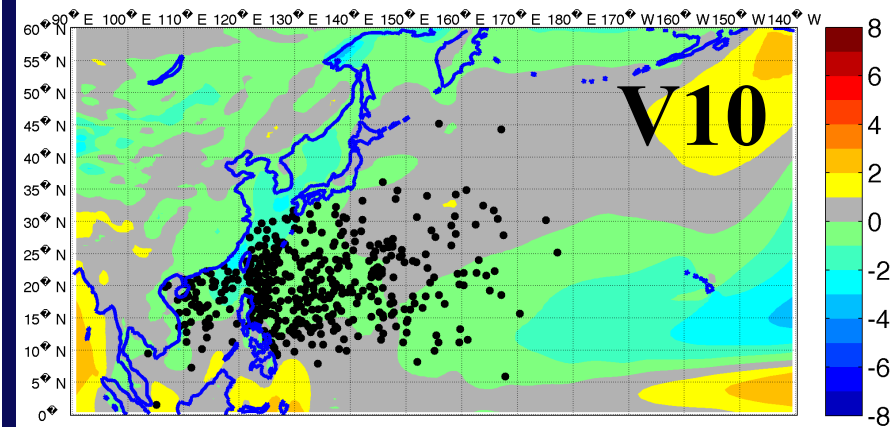


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ERA-INTERIM 1989-2009 U -TYPHOON INDUCED ANOMALY- [m/s]

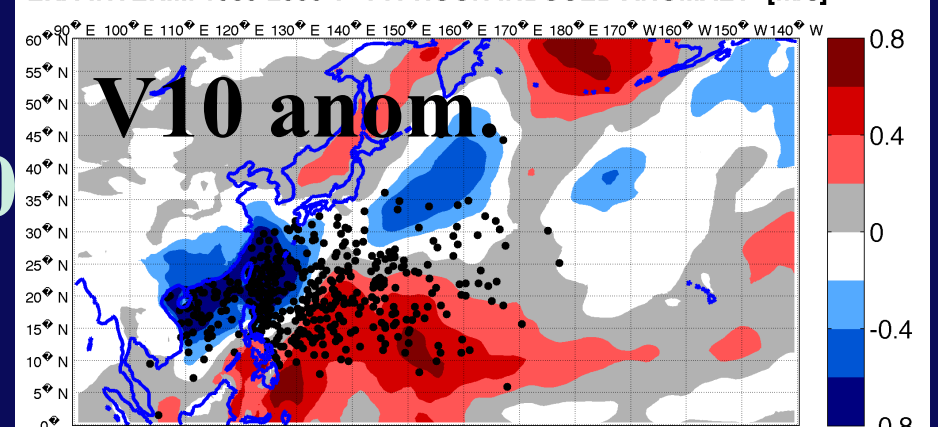


ERA-INTERIM 1989-2009 V June-December average [m/s]

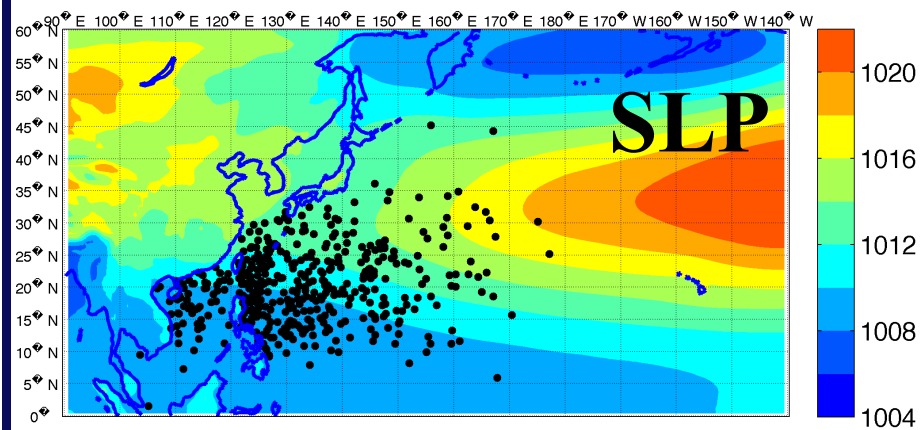


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ERA-INTERIM 1989-2009 V -TYPHOON INDUCED ANOMALY- [m/s]

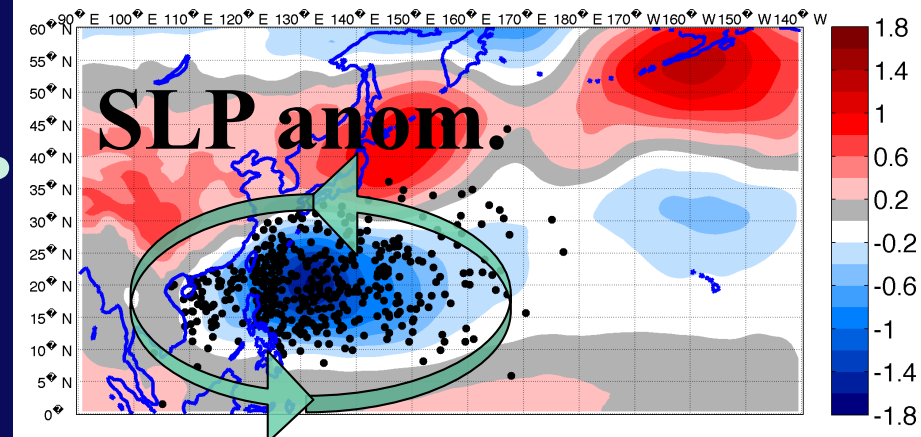


ERA-INTERIM 1989-2009 SLP June-December average [mb]

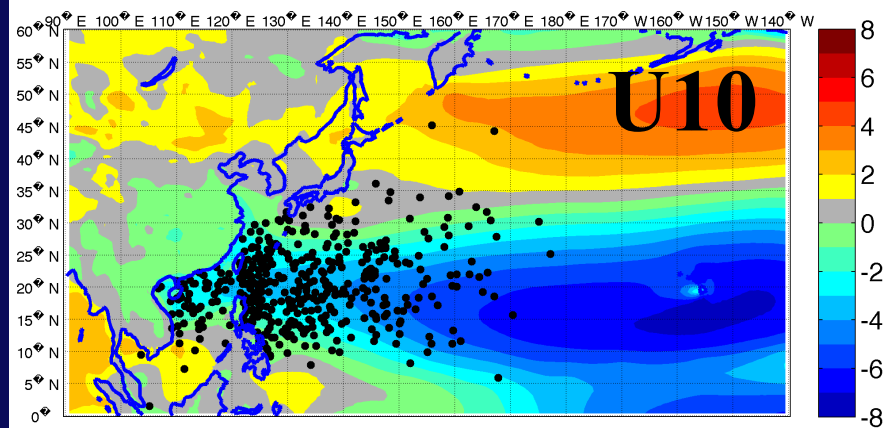


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ERA-INTERIM 1989-2009 SLP -TYPHOON INDUCED ANOMALY- [mb]

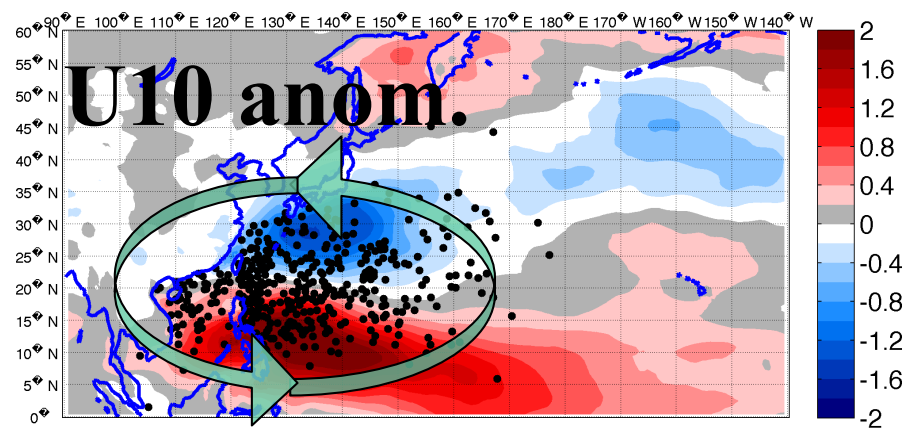


ERA-INTERIM 1989-2009 U June-December average [m/s]

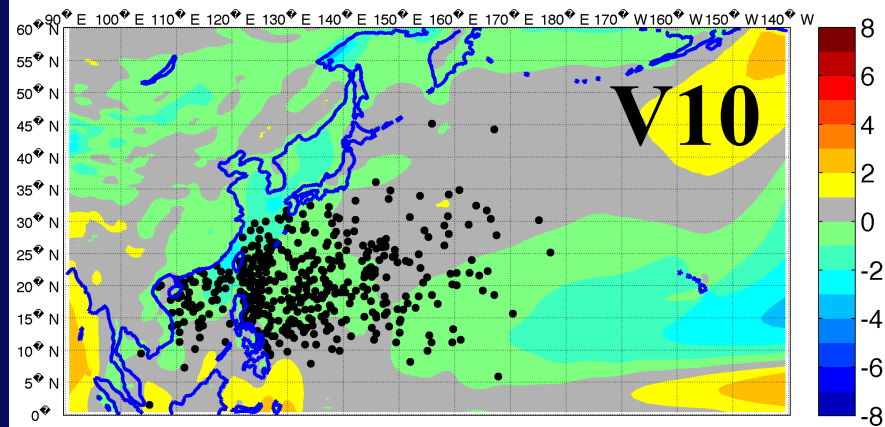


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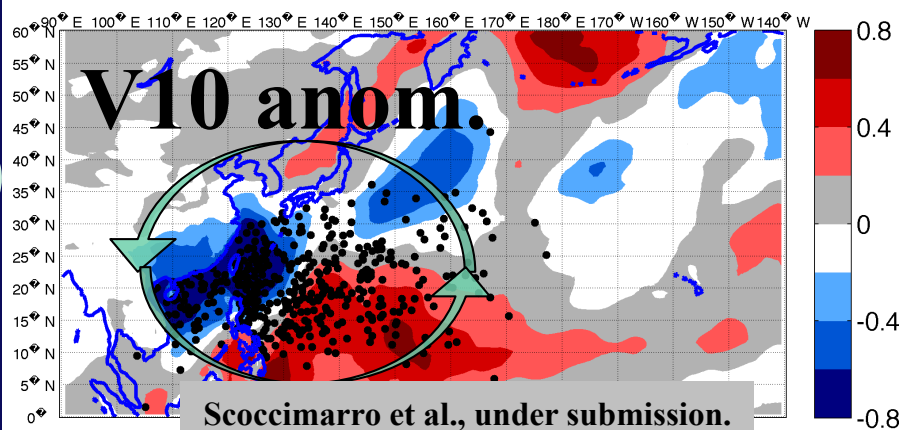


ERA-INTERIM 1989-2009 V June-December average [m/s]



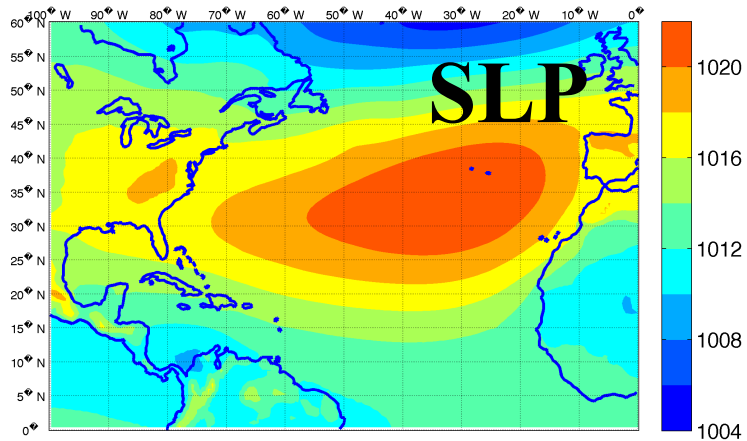
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ERA-INTERIM 1989-2009 V -TYPHOON INDUCED ANOMALY- [m/s]

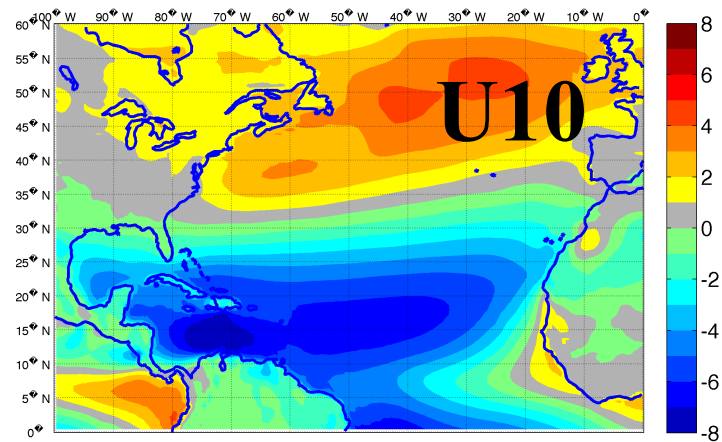


Scoccimarro et al., under submission.

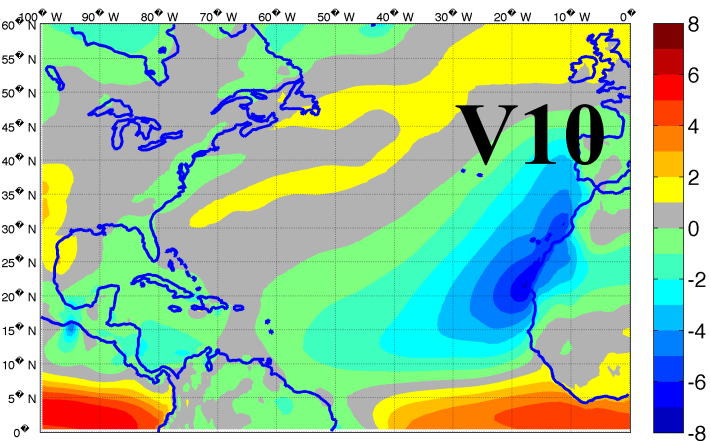
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ERA-INTERIM 1989-2009 U June-December average [m/s]



ERA-INTERIM 1989-2009 V June-December average [m/s]



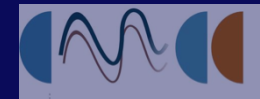
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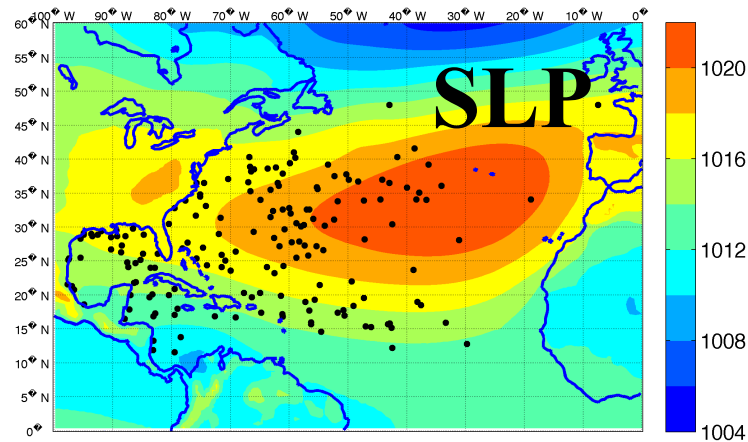
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1989-2009 June-December
ERA-Interim CLIMATOLOGY

Atlantic
(ATL)



ERA-INTERIM 1989-2009 SLP June-December average [mb]



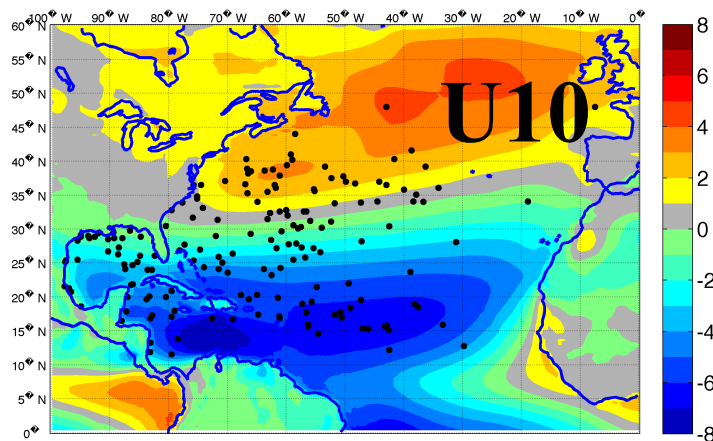
SLP

1989-2009 June-December
ERA-Interim CLIMATOLOGY

+

HURRICANES max intensity location
(black dots: 128 H considered
->7.5 H/year [Webster et al. 2005])

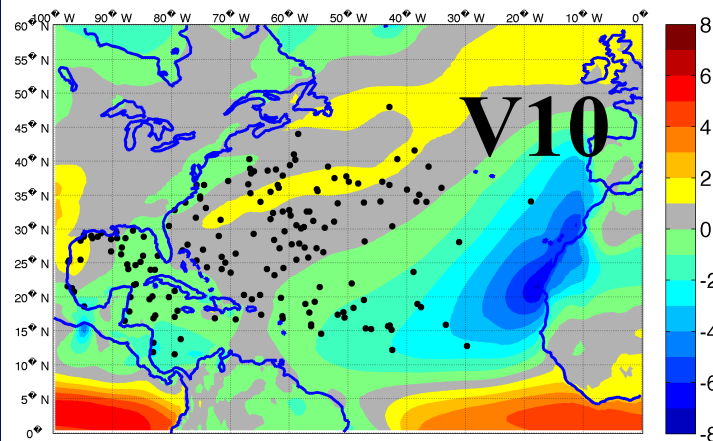
ERA-INTERIM 1989-2009 U June-December average [m/s]



U10

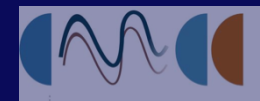
Atlantic
(ATL)

ERA-INTERIM 1989-2009 V June-December average [m/s]

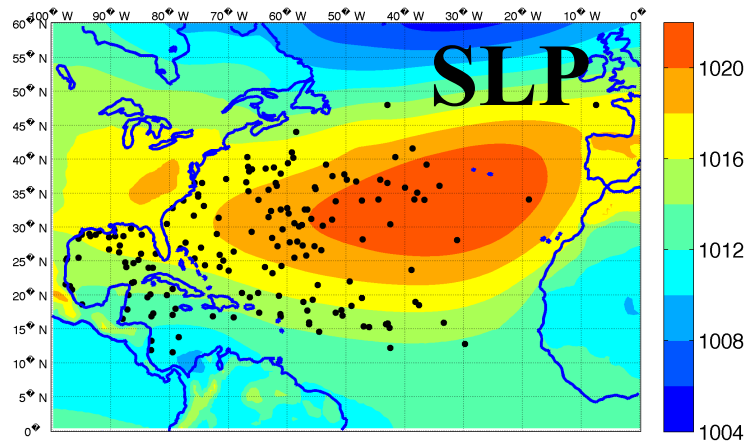


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Composite TC induced anomalies
computation on a daily time basis
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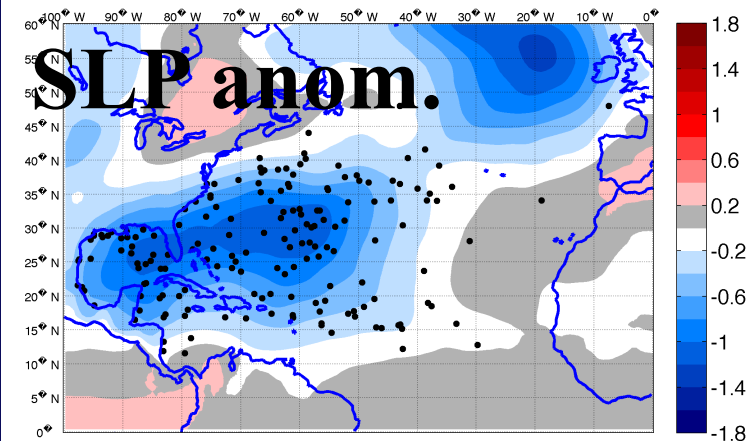


ERA-INTERIM 1989-2009 SLP June-December average [mb]

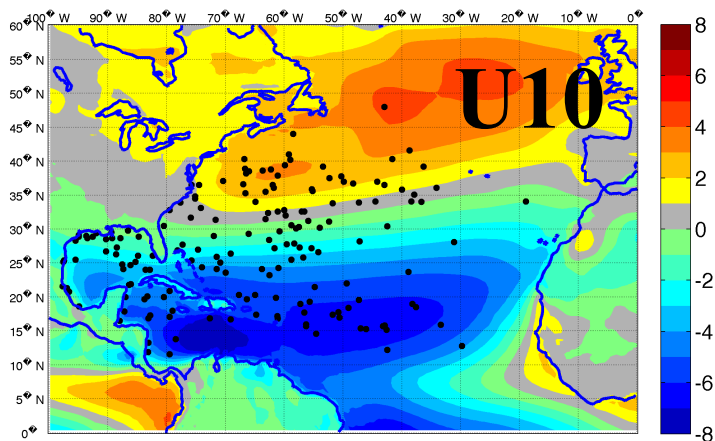


SLP

ERA-INTERIM 1989-2009 SLP -HURRICANE INDUCED ANOMALY- [mb]

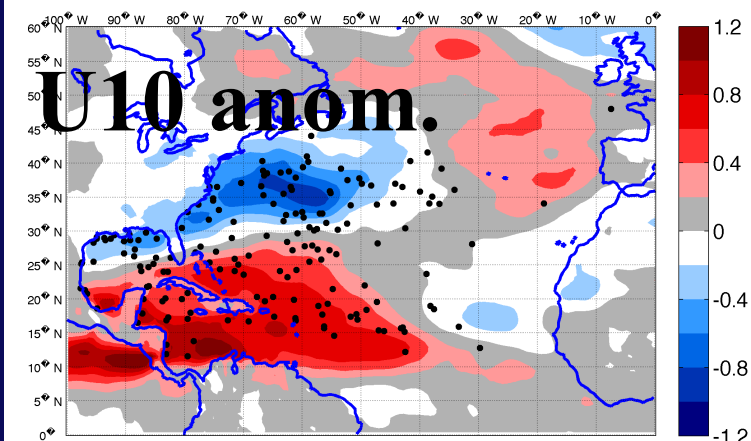


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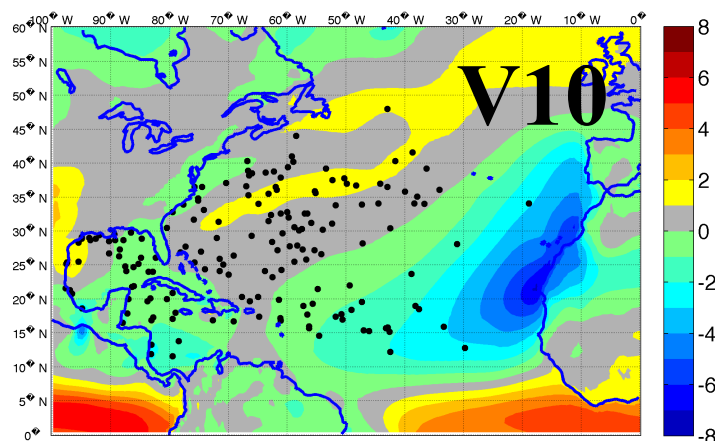


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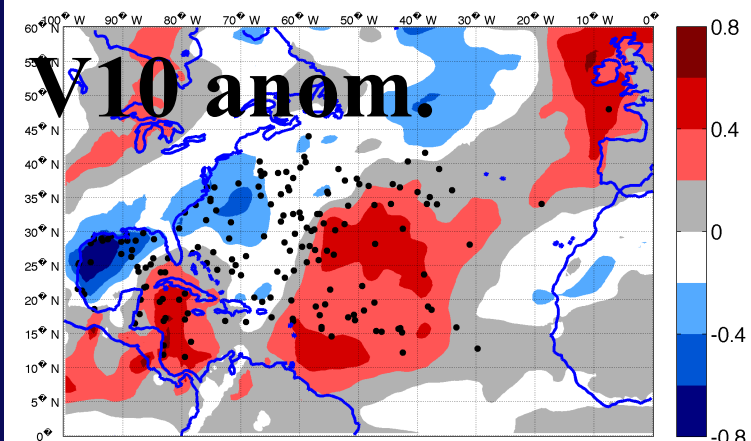


ERA-INTERIM 1989-2009 V June-December average [m/s]

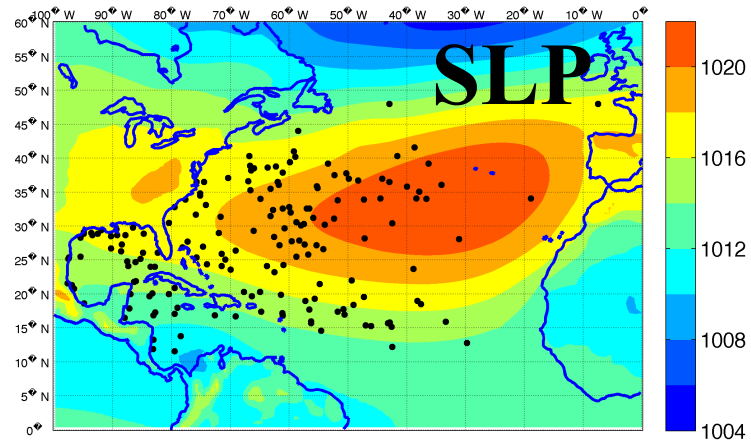


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ERA-INTERIM 1989-2009 V -HURRICANE INDUCED ANOMALY- [m/s]

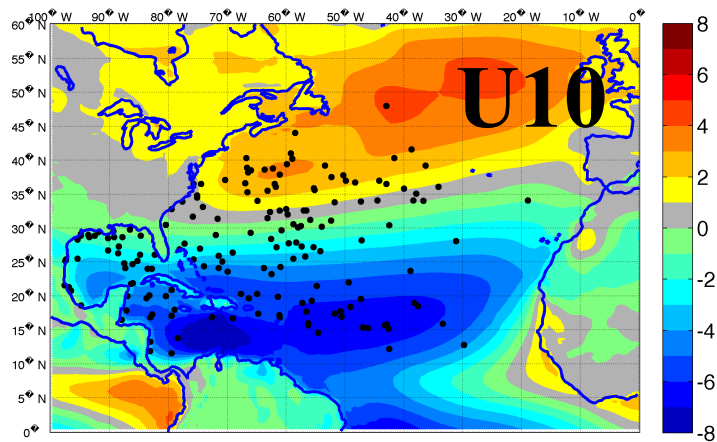


ERA-INTERIM 1989-2009 SLP June-December average [mb]



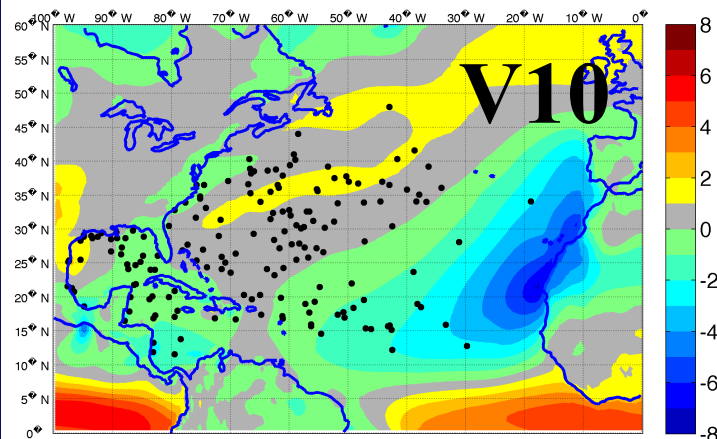
SLP

ERA-INTERIM 1989-2009 U June-December average [m/s]



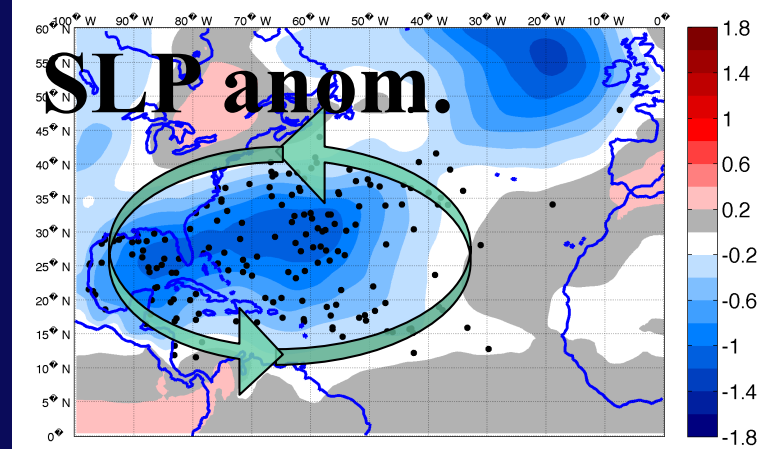
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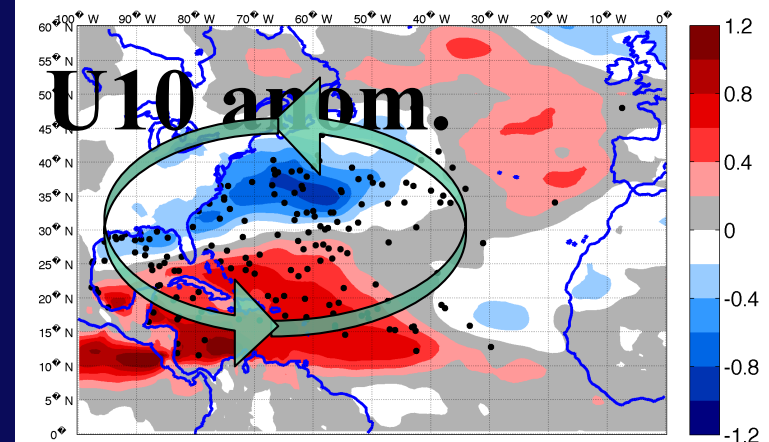


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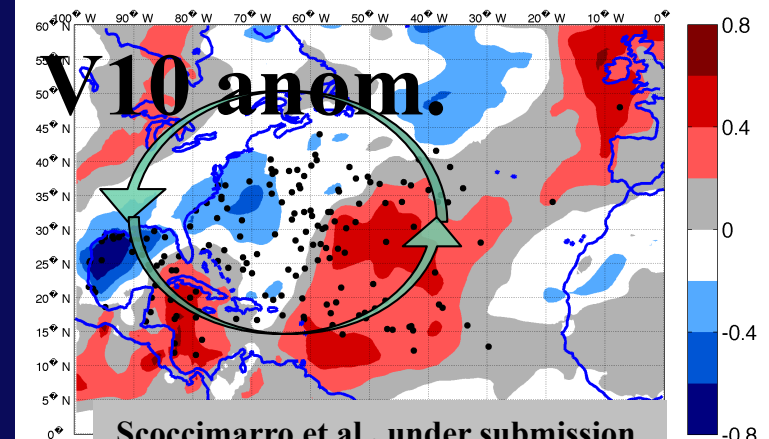
ERA-INTERIM 1989-2009 SLP -HURRICANE INDUCED ANOMALY- [mb]



ERA-INTERIM 1989-2009 U -HURRICANE INDUCED ANOMALY- [m/s]

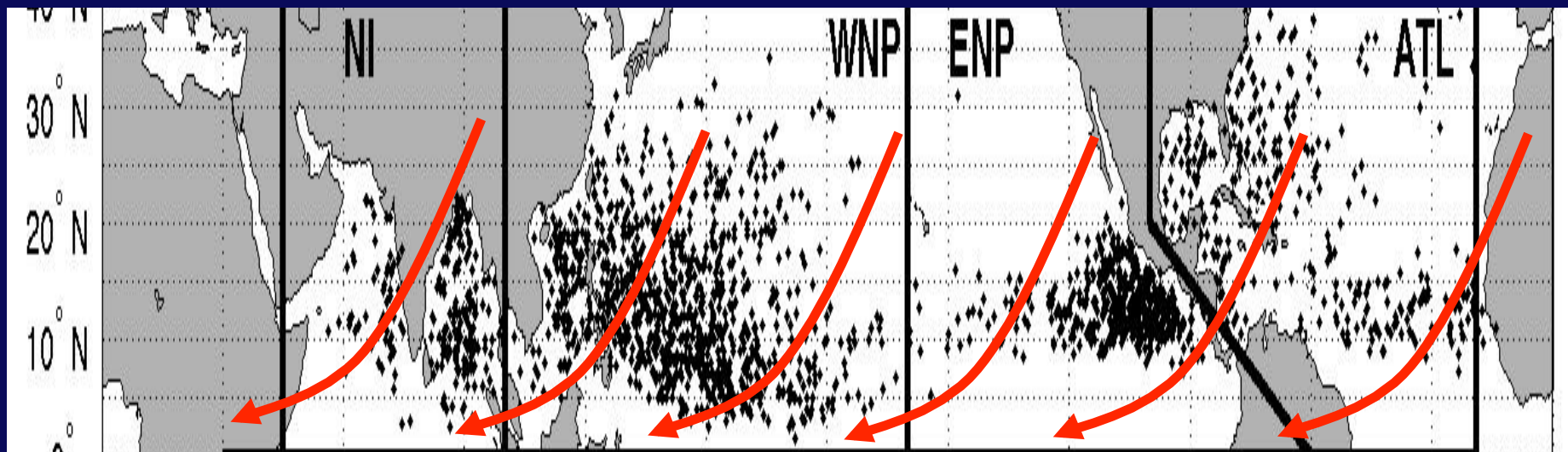


ERA-INTERIM 1989-2009 V -HURRICANE INDUCED ANOMALY- [m/s]

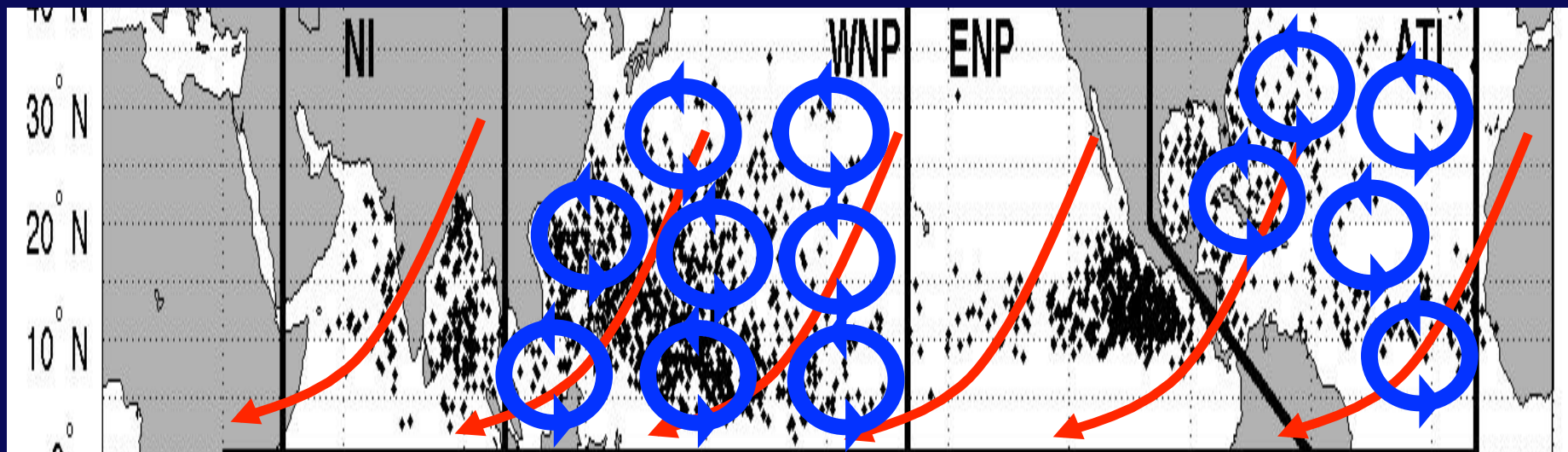


Scoccimarro et al., under submission.

Tropical Composite Cyclones over Atlantic and Pacific Oceans

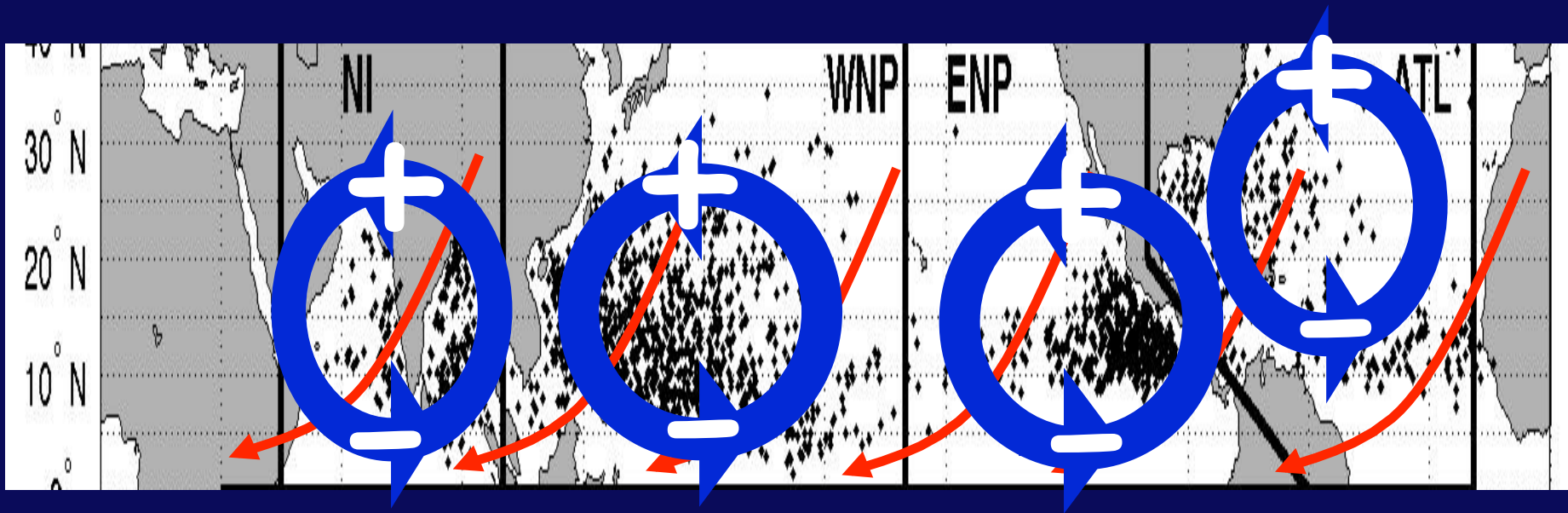


Tropical Composite Cyclones over Atlantic and Pacific Oceans



Tropical Composite Cyclones over Atlantic and Pacific Oceans

+ reinforces trade winds inducing negative anomalies



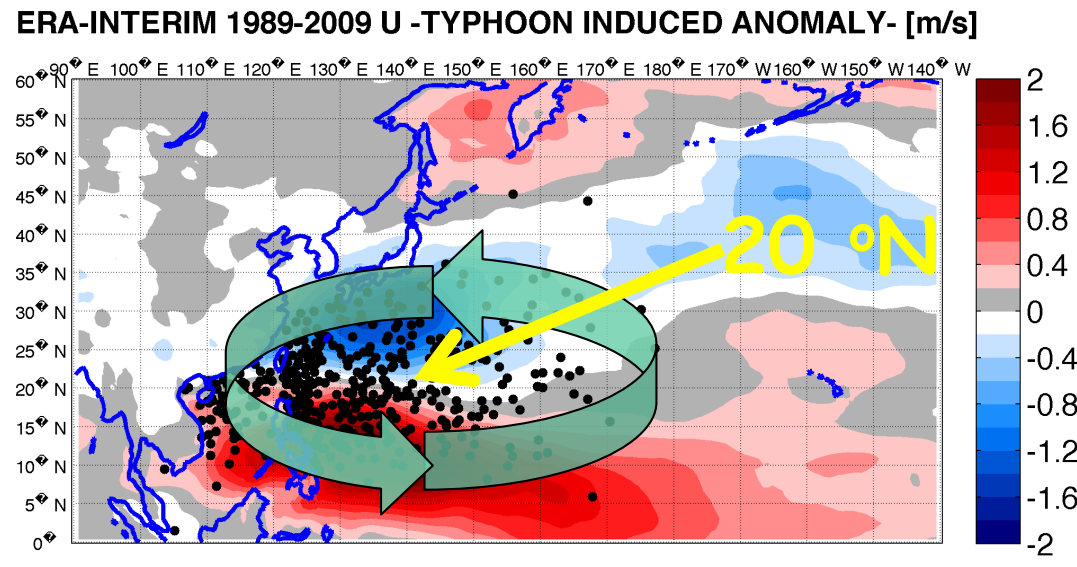
— Weaken trade winds inducing positive anomalies

Tropical Composite Cyclones over Atlantic and Pacific Oceans

WNP

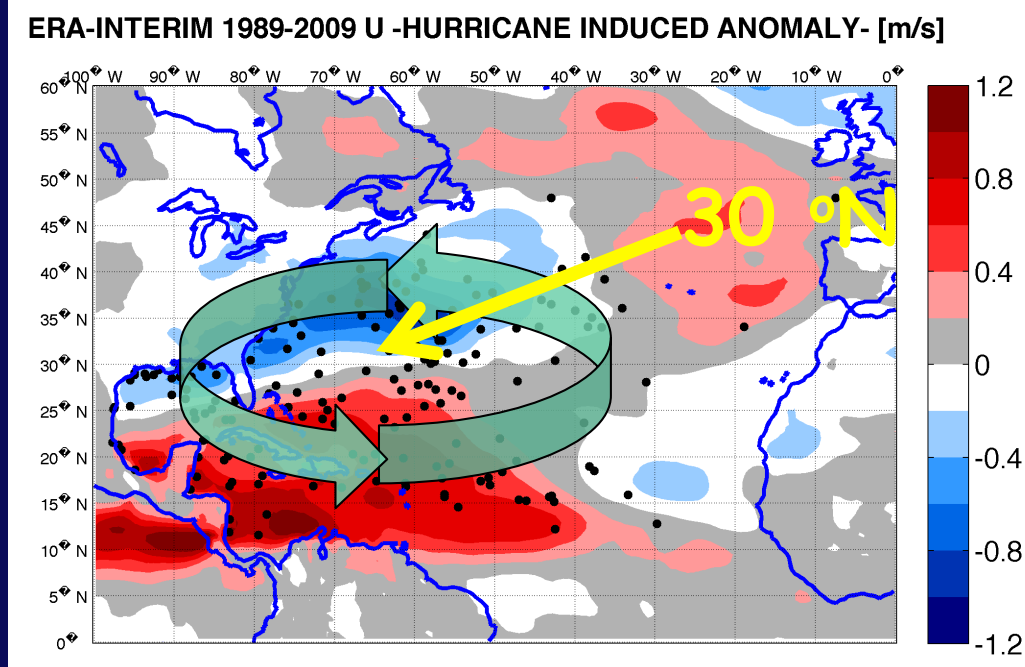
WNP TCC

U10



TCC center is
in accord with
PDF of observed
latitudinal distribution
of
Typhoon/hurricane
events

ATL TCC



ATL

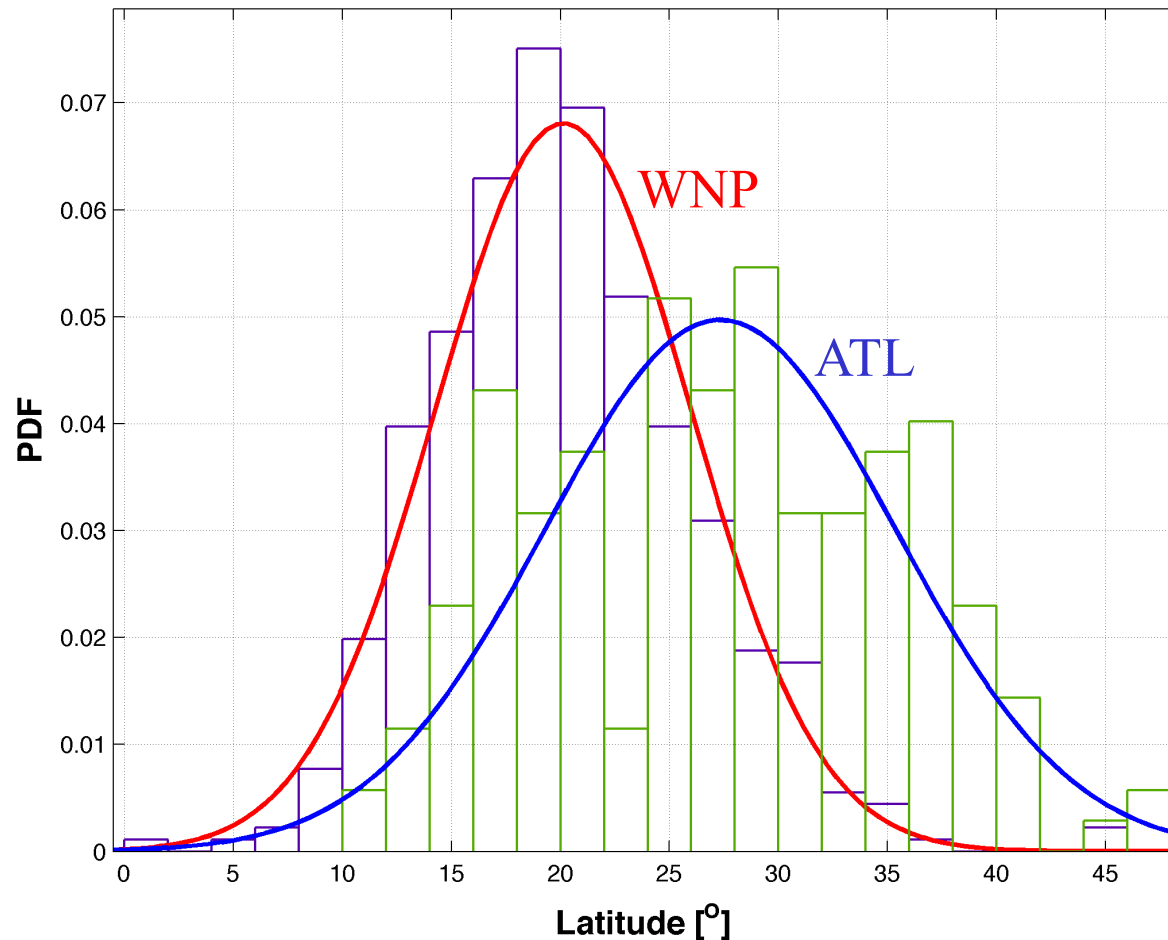


Scoccimarro et al., under submission.



Tropical Composite Cyclones over Atlantic and Pacific Oceans

PDF of WNP and ATL typhoon/hurricane location [meridional distribution]



TCC center is
in accord with
PDF of observed
latitudinal distribution
of
Typhoon/hurricane
events

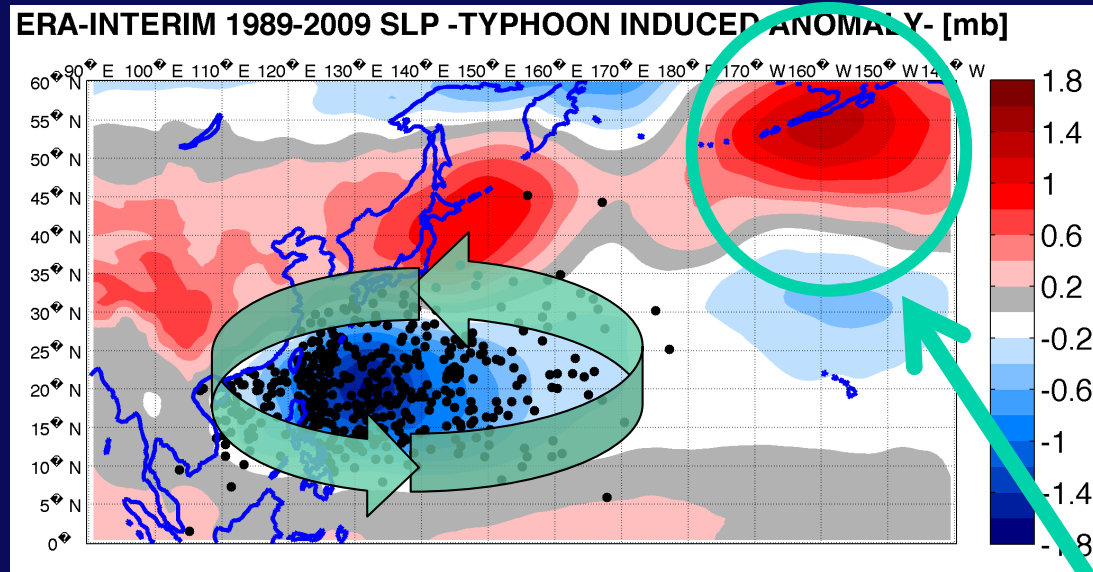


Tropical Composite Cyclones over Atlantic and Pacific Oceans

WNP TCC

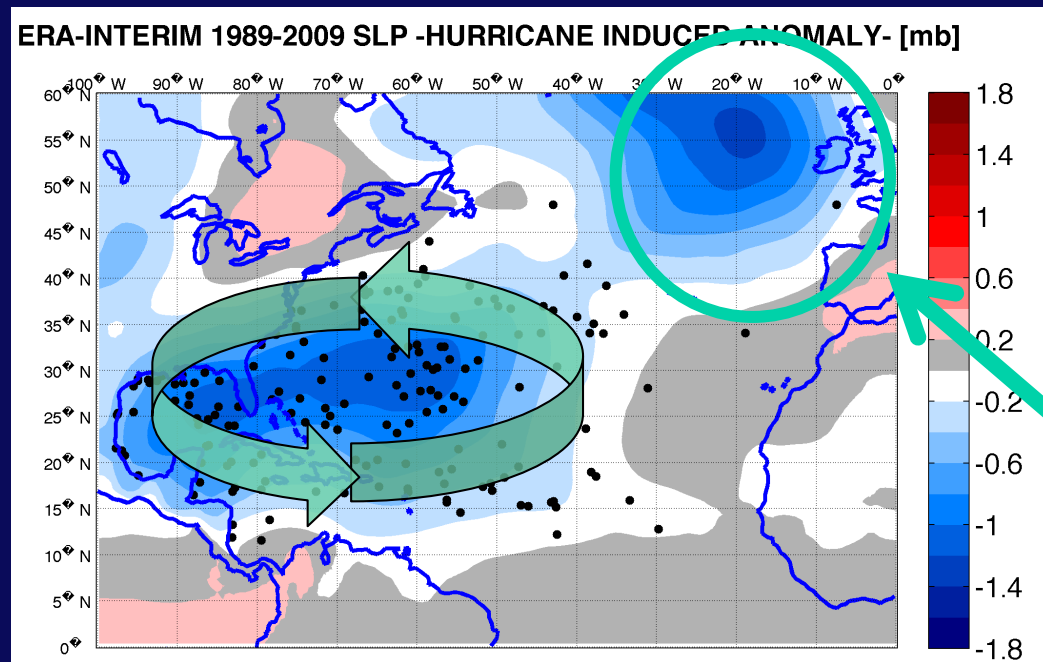
SLP

ATL TCC



TCC induced SLP anomalies interest also the subpolar low pressure belt

'Aleutian low' region results affected by positive SLP anomaly induced by Typhoons



N-E Atlantic interested by a negative SLP Hurricane induced anomaly



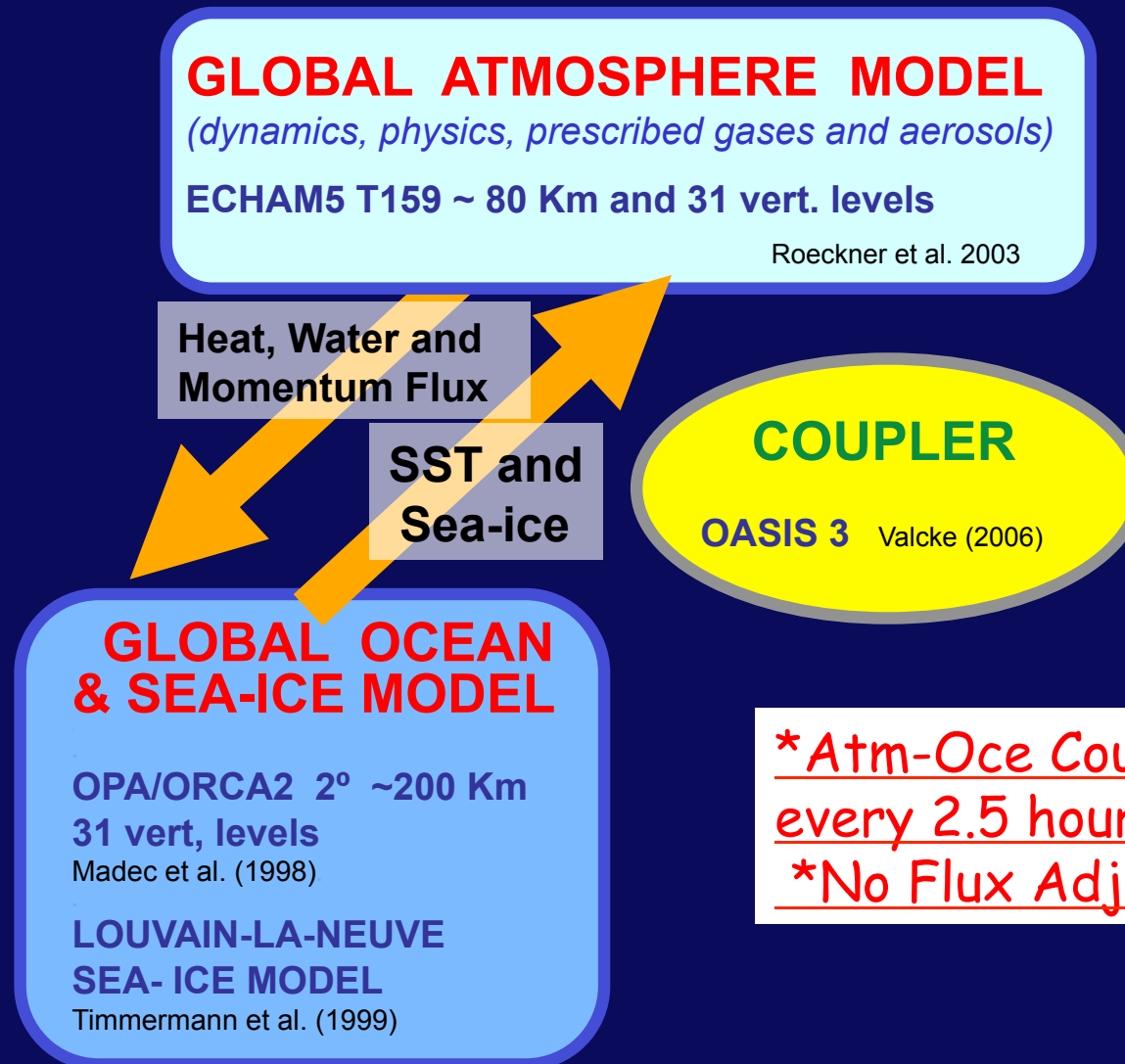
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TCC interplay with the ocean: results from a fully coupled hi-res
"Hurricane Resolving" High-Resolution Coupled General Circulation Model
(CMCC_MED evolution of INGV-SXG [Gualdi et al., JoC 2008])

This model is now running CMCC CMIP5 IPCC scenario exps

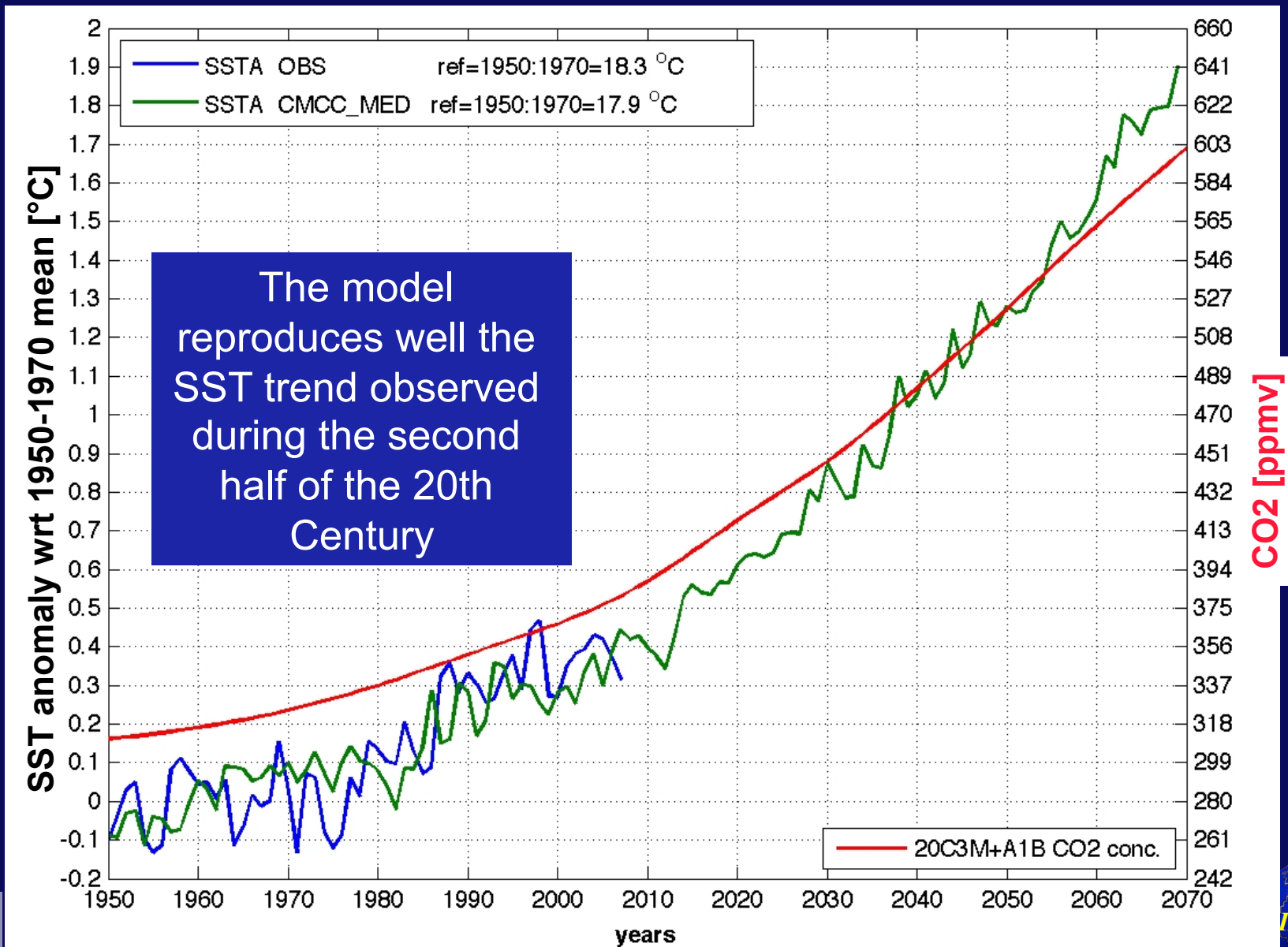


*Atm-Oce Coupling
every 2.5 hours
*No Flux Adjustment



The CMCC climate simulation : 20C3M and A1B scenario

Evolution of the global mean SST Anomaly from 1950 to 2069: observation vs. model

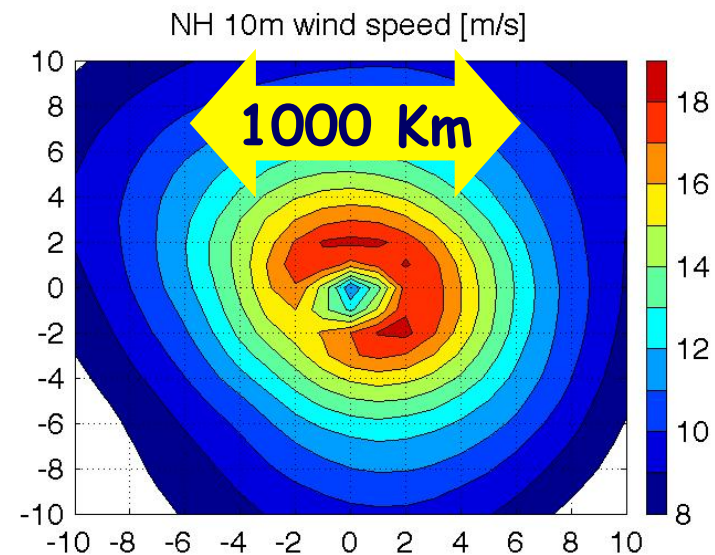
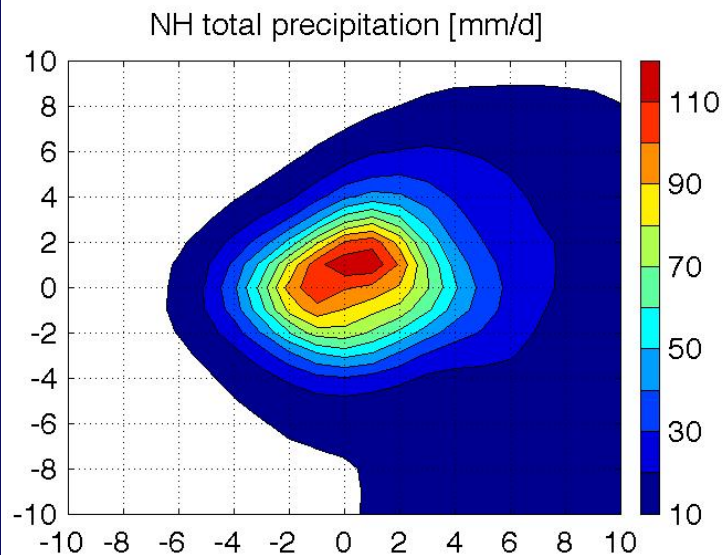


How the model represent Tropical Cyclones

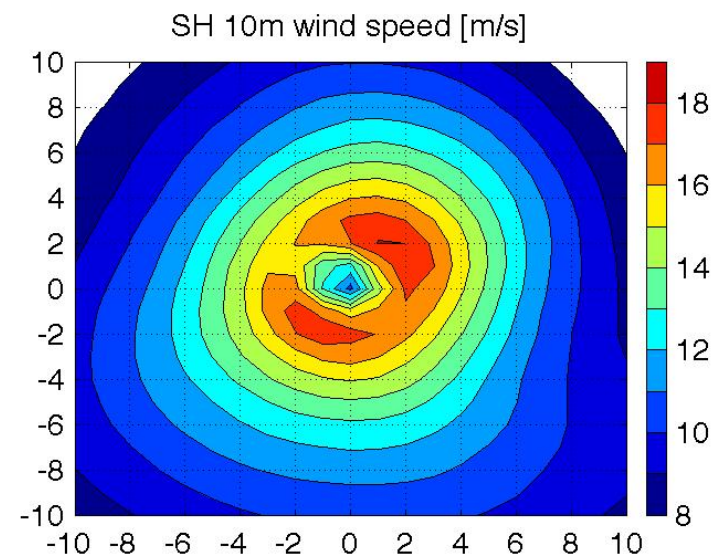
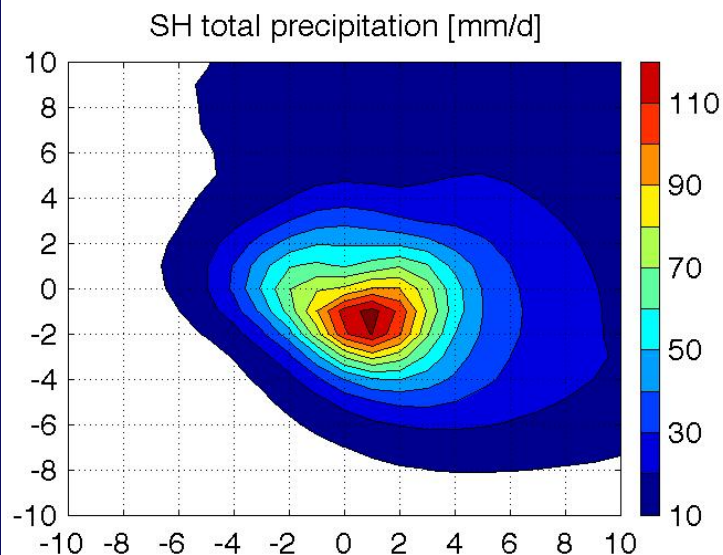
Composite of 100 hemispheric most intense simulated TCs

[TC-MIP CSIRO TCs detection method http://www.earthsci.unimelb.edu.au/~kwalsh/tcmip_index.html]

NH



SH



PRECIPITATION

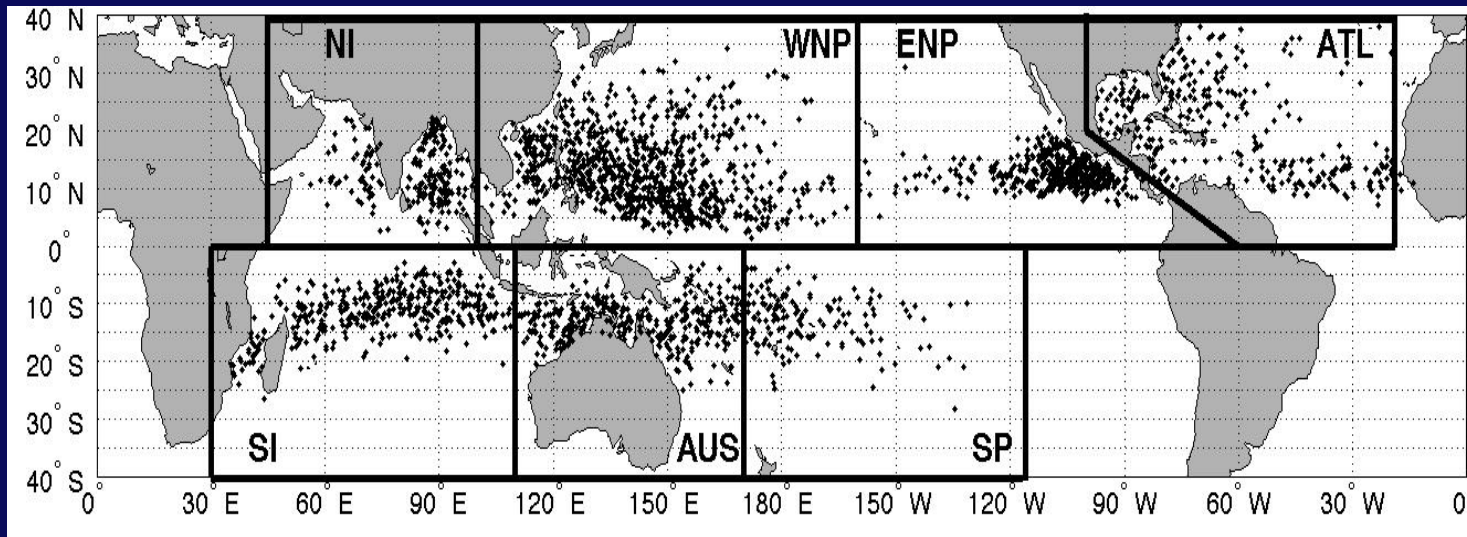
10m WIND SPEED



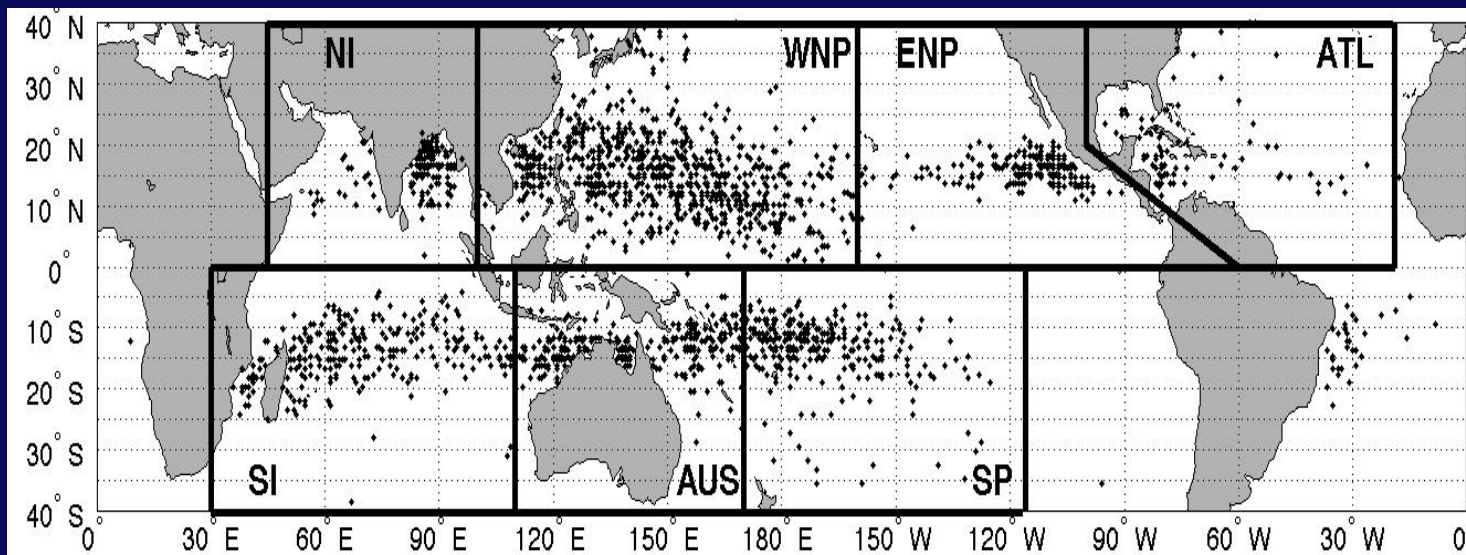
How the model represent Tropical Cyclones

TCs track starting points during 1970:1999

OBS



MODEL

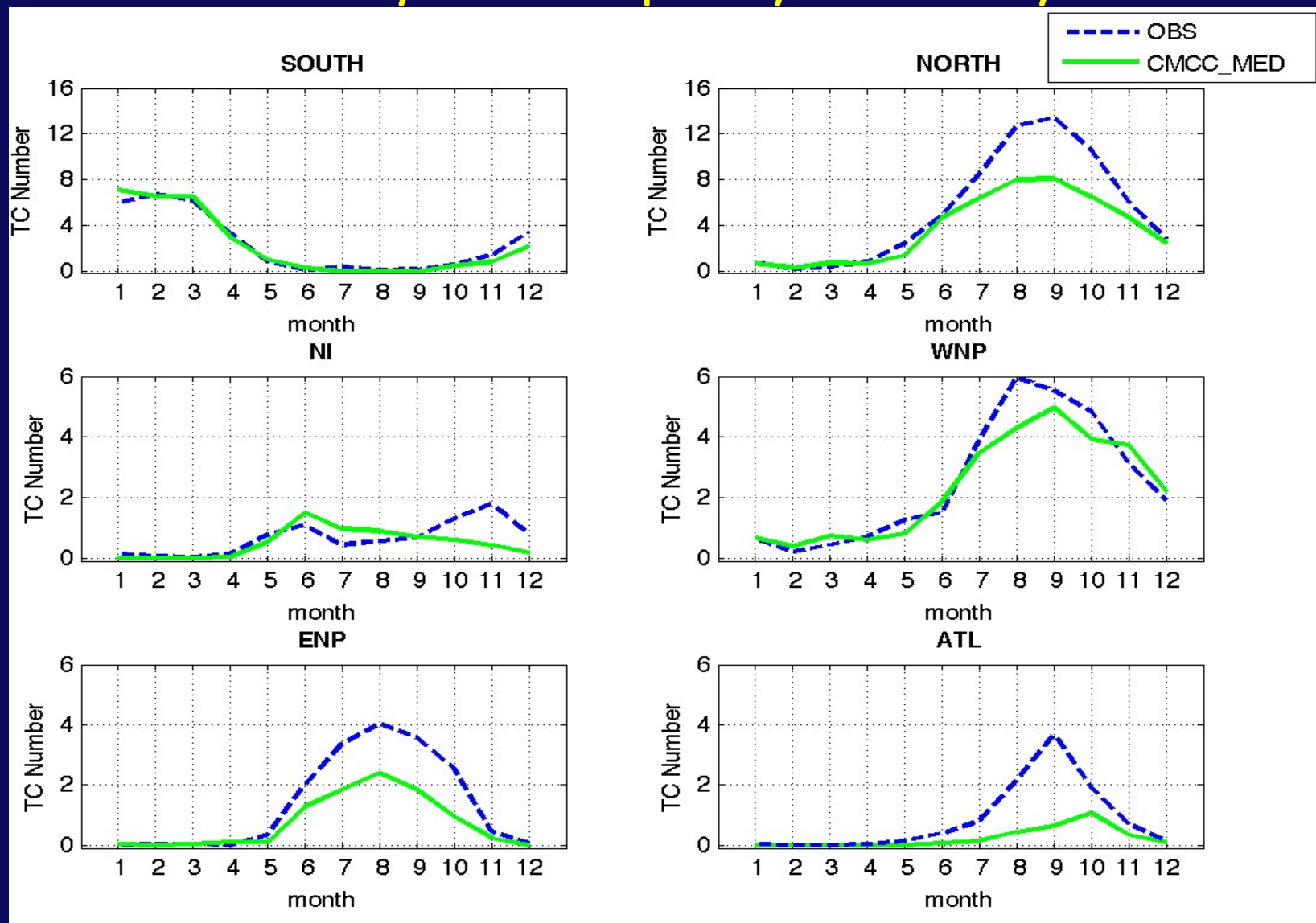


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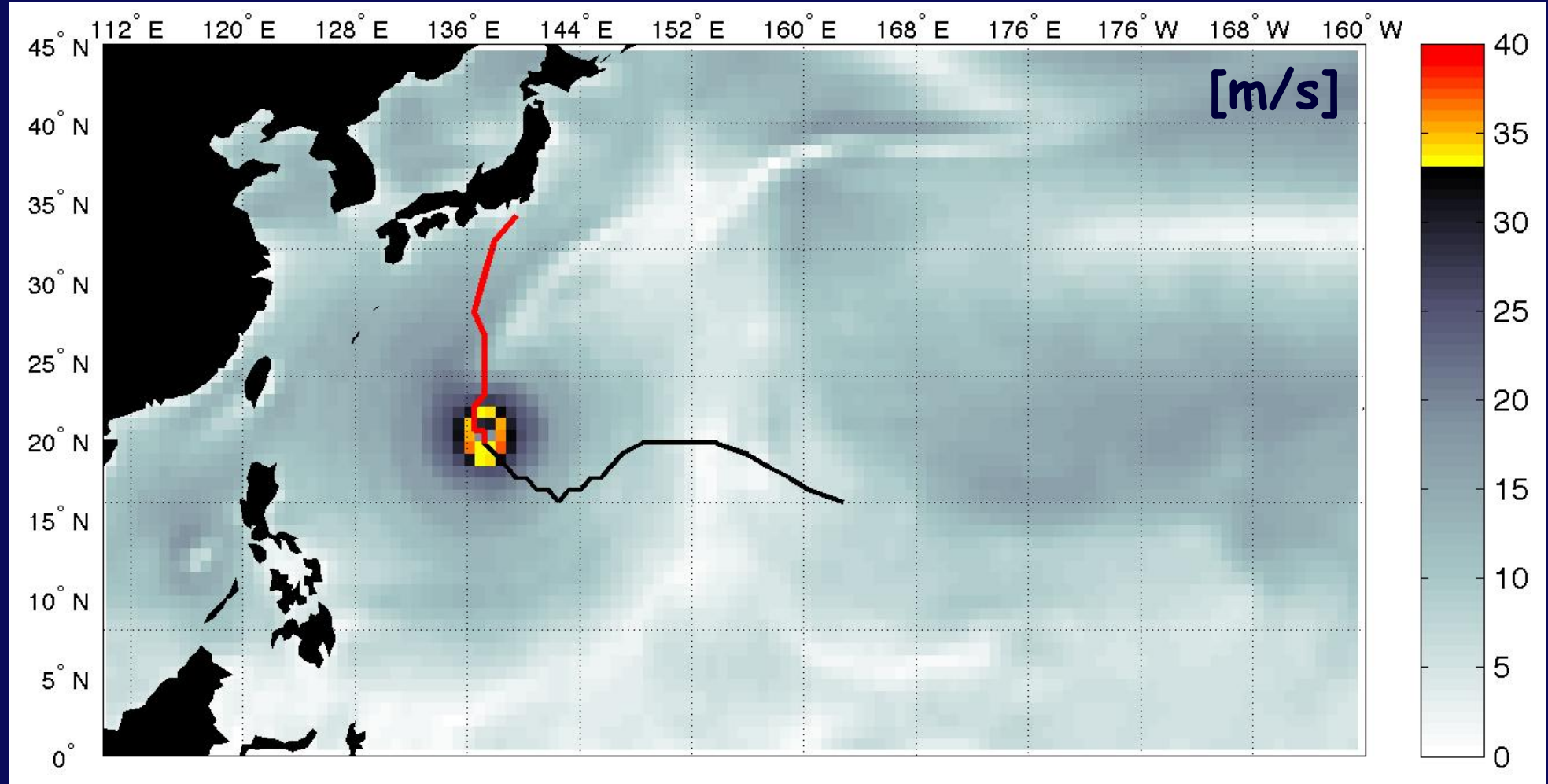
How the model represent Tropical Cyclones

Seasonality of the Tropical Cyclone Activity



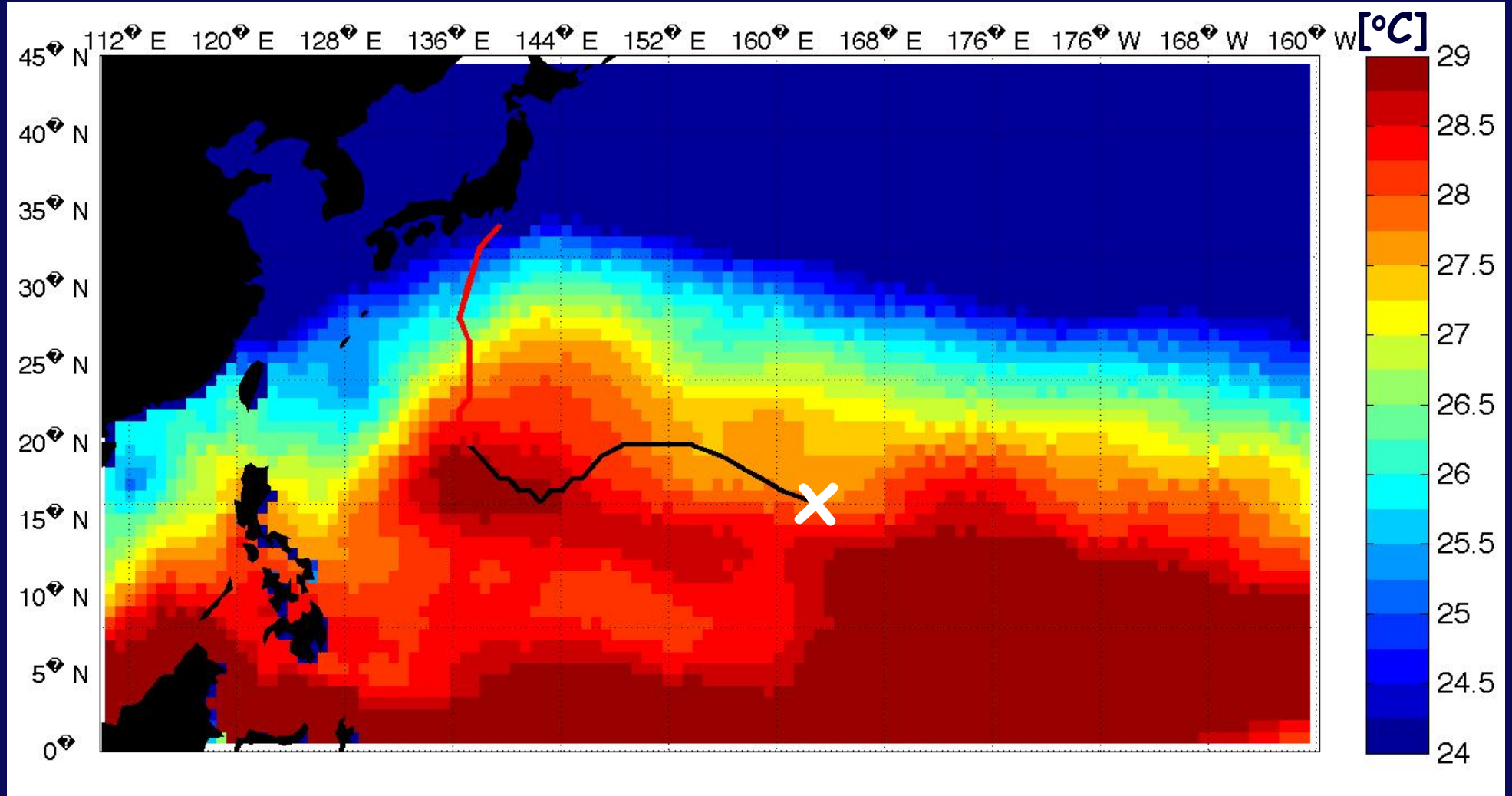
Modelled TC interaction with the ocean

10 meter max wind speed associated to a simulated cat1 typhoon



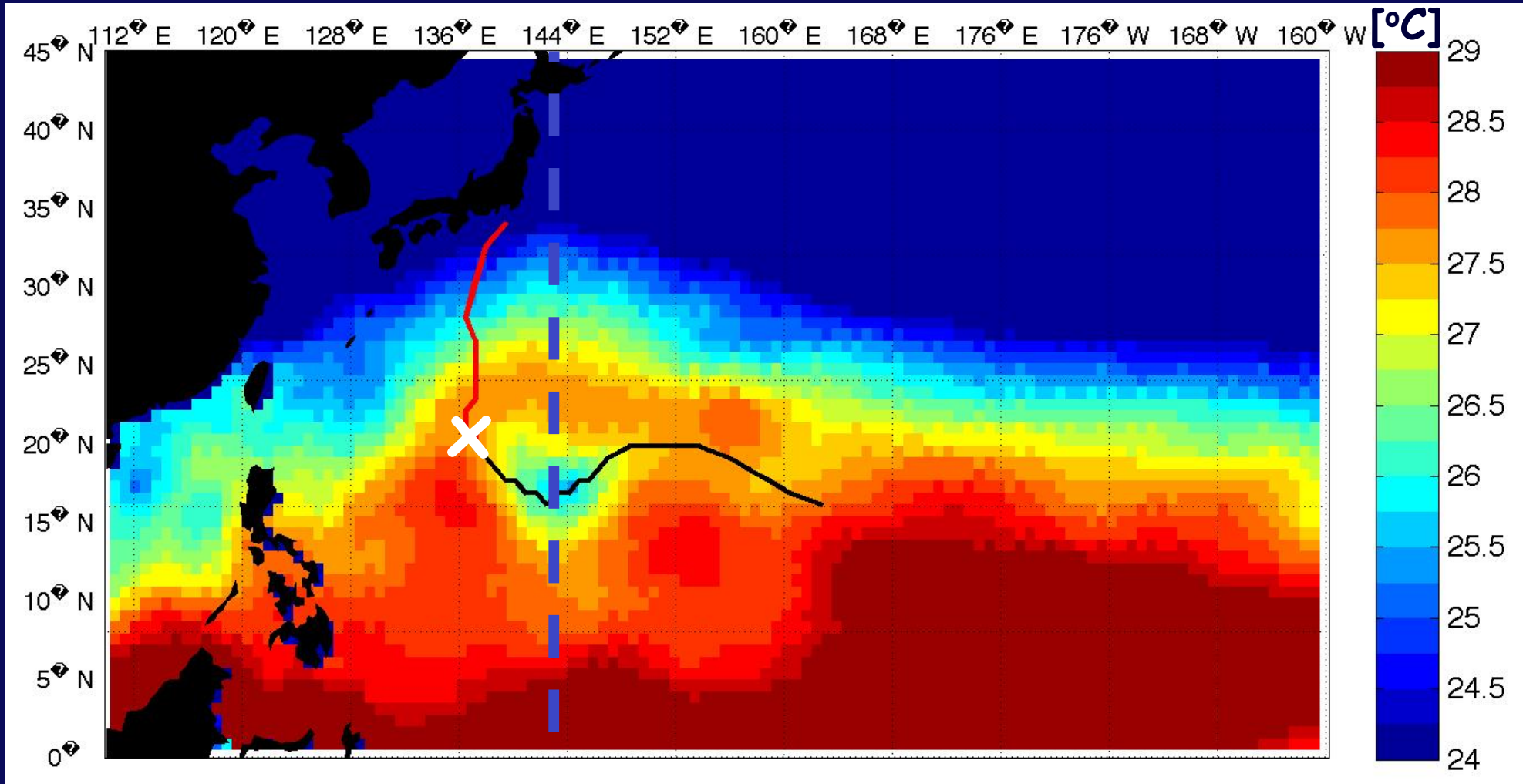
Modelled TC interaction with the ocean

SST associated to a simulated cat1 typhoon: before

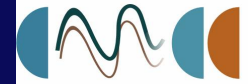


Modelled TC interaction with the ocean

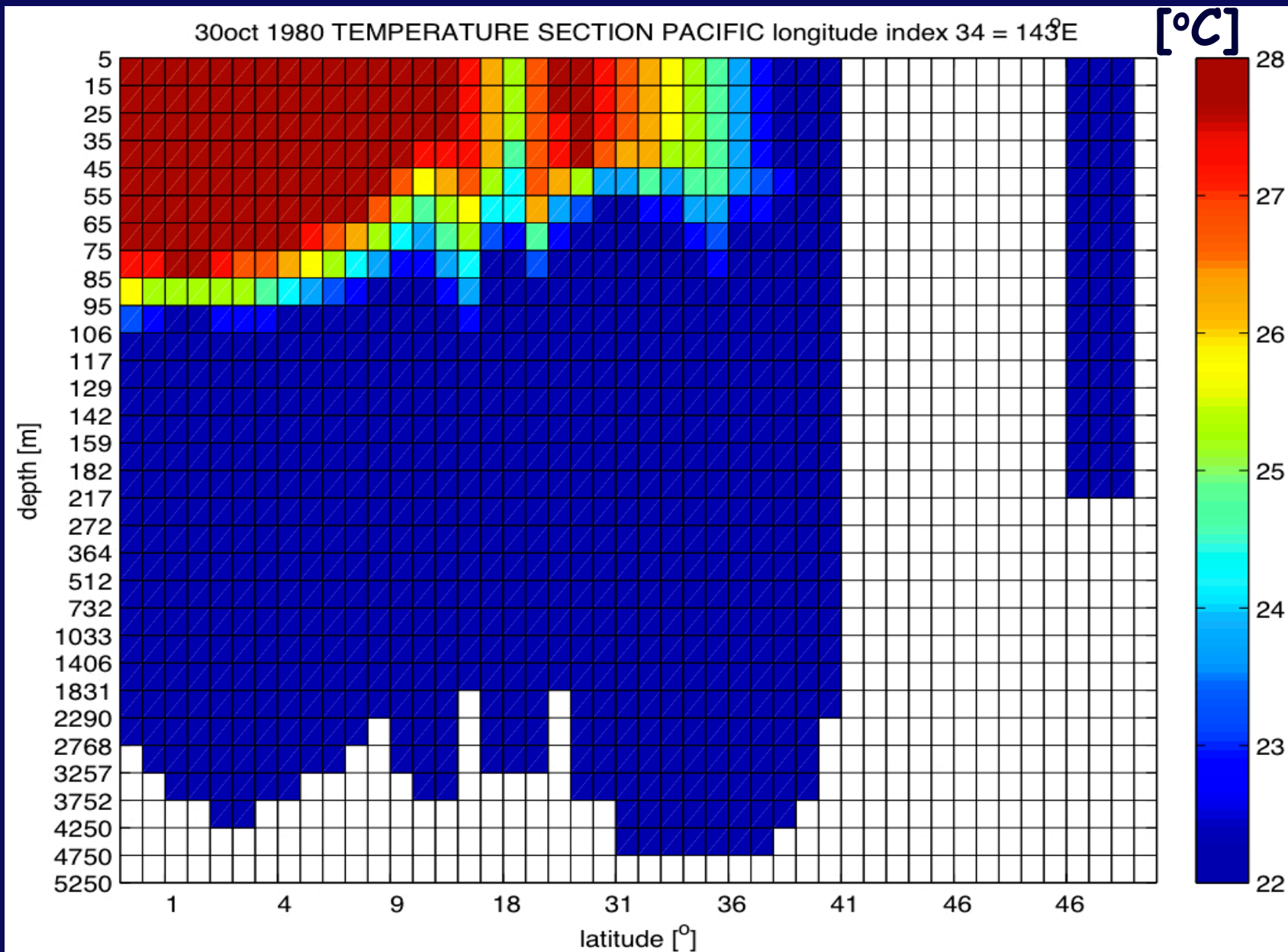
SST associated to a simulated cat1 typhoon: after



Modelled TC interaction with the ocean



Sea Surface Cooling induced by a simulated cat1 typhoon



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How TCs affect the Ocean Heat Transport

Previous studies:

The ocean response to moving Tropical Cyclones (TCs) has been studied through coupled numerical experiments (*) and there is evidence that the TC activity plays a role in the thermodynamic of the ocean (**).

There is therefore evidence that TCs can transfer a significant amount of heat and momentum into the ocean (***), suggesting that TCs could affect the global climate system.

Recent studies (****) indicate that the TC induced heat anomalies do not propagate under the winter termocline, thus the annual OHT average is not affected.

(*) [Chang & Anthes 1979, Sutyrin & Khain 1979, Shade and Emanuel, 1999]

(**) [Emanuel 2001]

(***) [Emanuel 2001, Srivier and Huber 2007, Pasquero and Emanuel 2008, Liu et al., 2008]

(****) [Jansen 2010]

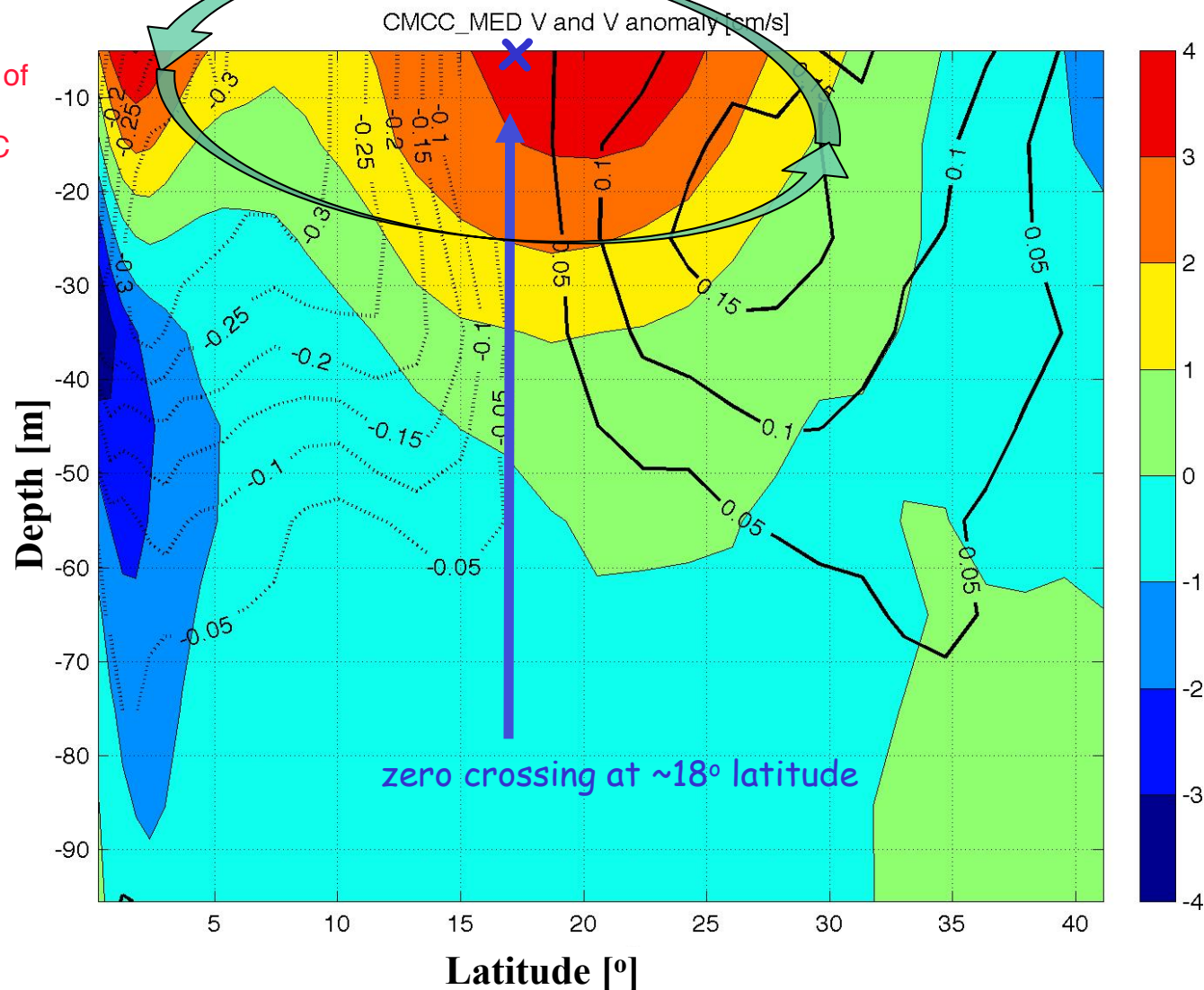


the TCC fingerprint on the ocean

Meridional Velocity anomaly induced by TCs:

V jun-dec mean (colors [cm/s]) and V anomaly (contours [cm/s])

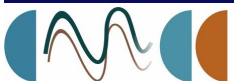
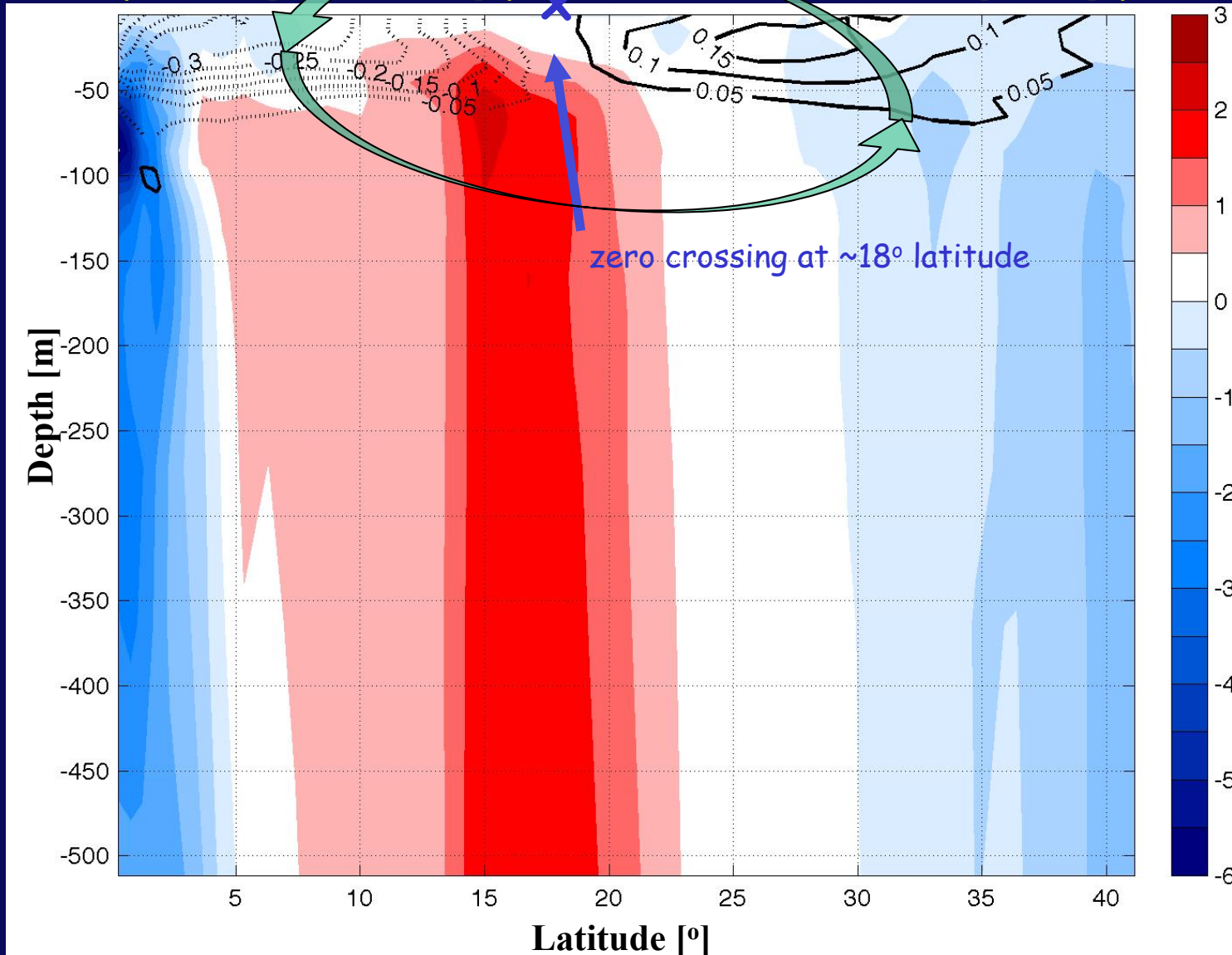
The anomalies have been computed (and averaged) for 20 days around the day of maximum intensity ($t_{wimax} \pm 10dd$) of the TC with respect to the monthly climatology (1970:1990) over the 100 most Intense TCs.



the TCC fingerprint on the ocean

Ocean Velocity Anomalies induced by TCs:

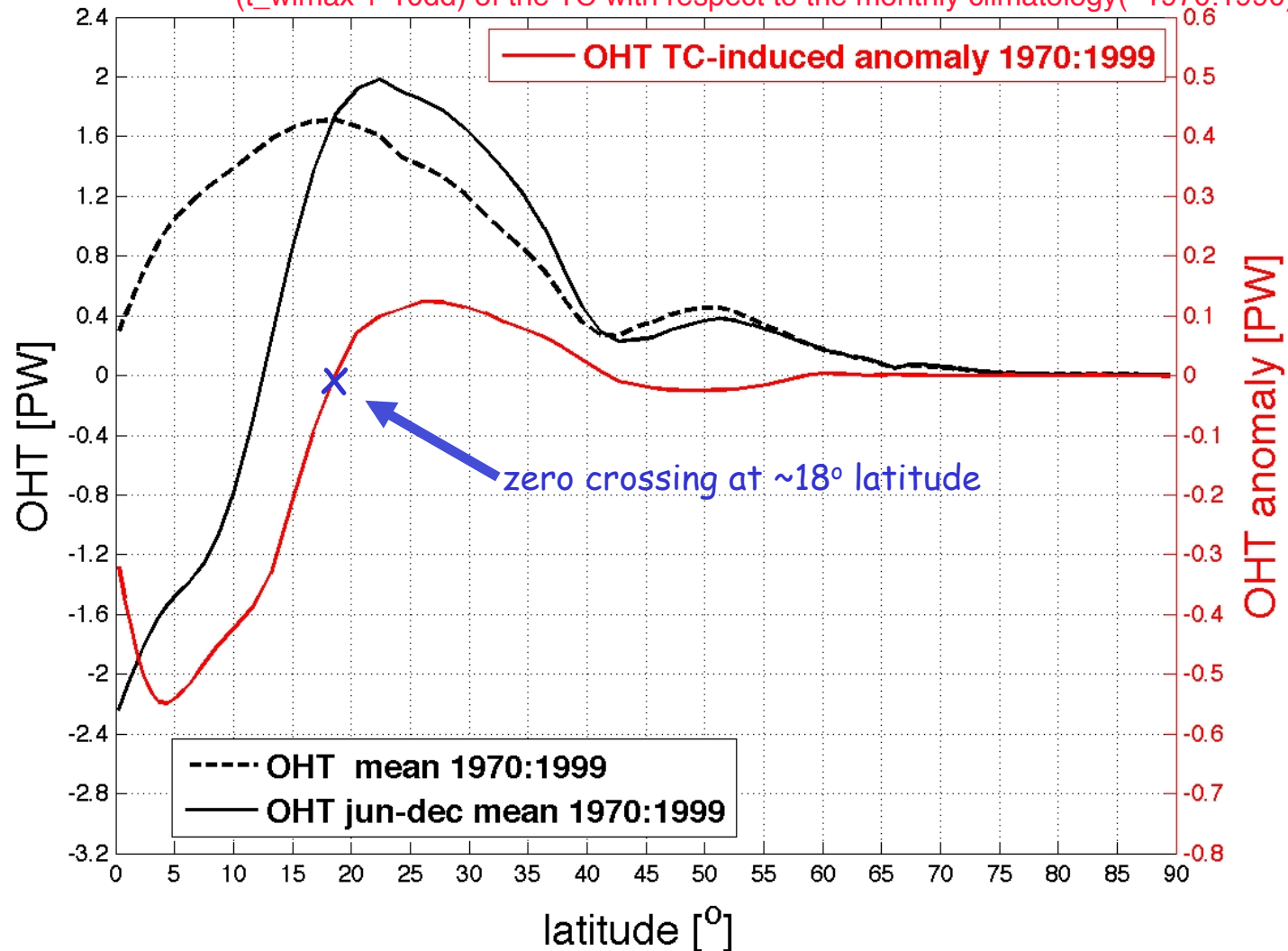
W (colors [10^{-5} cm/s]) and V (contours [cm/s])



How TCCs affect the Ocean Heat Transport

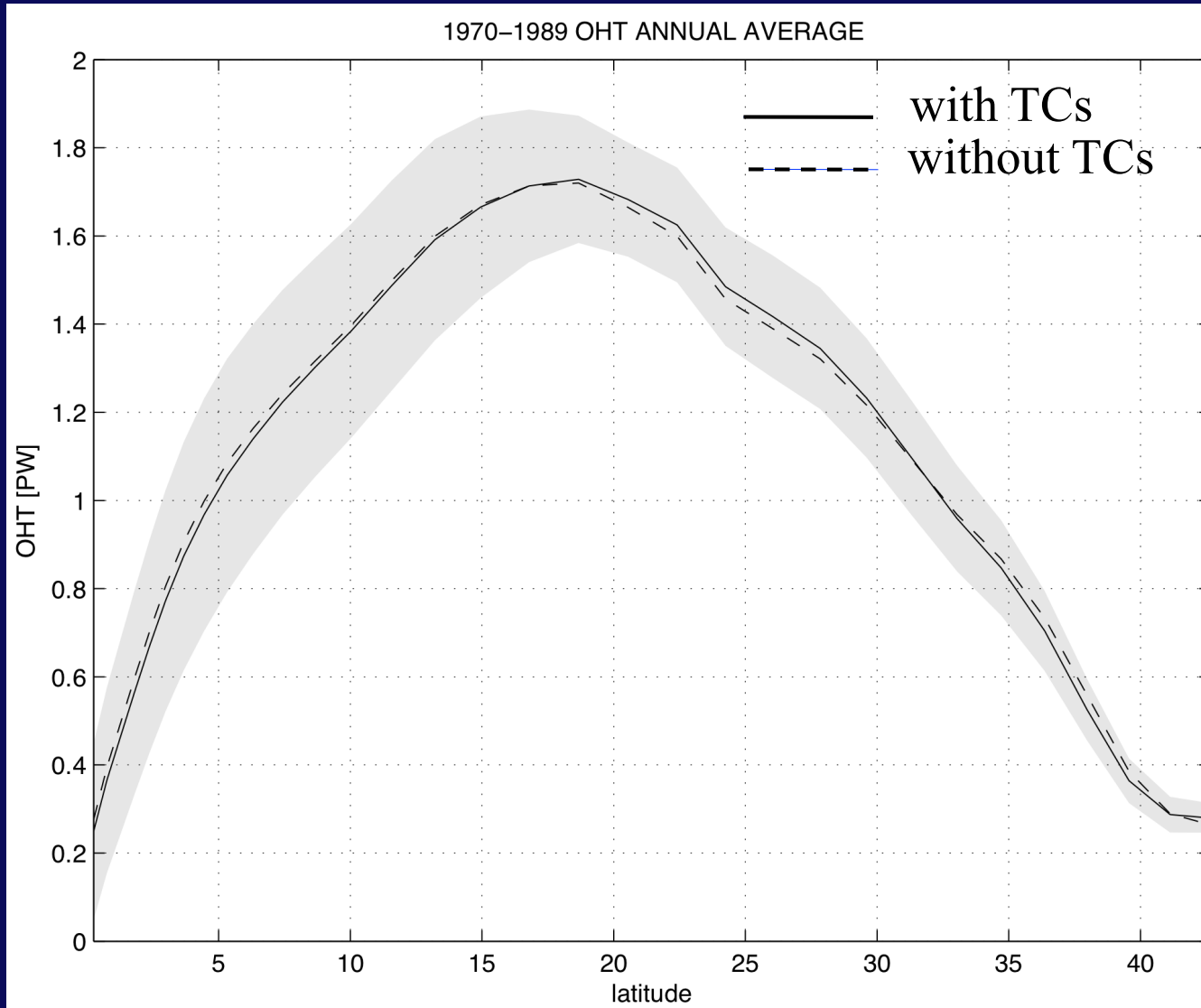
OHT as simulated by the model and TC induced OHT (TCiOHT) Anomaly

The anomalies have been computed (and averaged) for 20 days around the day of maximum intensity ($t_{wimax} \pm 10dd$) of the TC with respect to the monthly climatology (1970:1999)



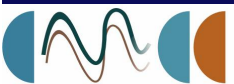
TCs activity under the 21st century (A1B scenario)

OHT with and without TCs



The modelled heat anomalies below the mixed layer, induced by TCs on weekly time scales, do not propagate in the climatology:

Does it depend on the still too low modelled TC intensity?



The Tropical Composite Cyclones: the integrated effect of hurricanes on the ocean-atmosphere coupled system

CONCLUSIONS 1/2

The ERA-Interim data-set (atmospheric resolution $\sim 70\text{Km}$) is an interesting tool to investigate Tropical Cyclones (TCs) activity in the present climate.

A composite analysis for TC induced anomalies over SLP, U10 and V10 fields highlights wide cyclonic structures over the tropics, here defined as Tropical Composite Cyclones (TCC).

TCCs can help in investigating the relationship between TCs and the dominant variability modes of large scale atmospheric circulation.

The Tropical Composite Cyclones: the integrated effect of hurricanes on the ocean-atmosphere coupled system

CONCLUSIONS 2/2

TCCs act reinforcing trade winds at high tropical latitudes (20° - 35° N) and weaken them at low latitudes (5° - 20° N).

State of the art CGCMs can help in understanding TCs effect on the Ocean: The TCC induced overturning cells in the ocean velocity cause a Ocean Heat Transport (TCiOHT) anomaly:

The *Poleward* OHT *out of the tropics* increases (*) but also increases the OHT *into the deep tropics* (**) on weekly time scales without impact the yearly averaged large-scale meridional heat advection (***).

(*) [Emanuel, 2001]

(**) [Jansen & Ferrari, 2009]

(***) [Jansen 2010]



The Tropical Composite Cyclones: the integrated effect of hurricanes on the ocean-atmosphere coupled system

REFERENCES:

- Scoccimarro E., S.Gualdi, A.Bellucci, A.Sanna, P.G. Fogli, E.Manzini, M.Vichi, P.Oddo, A.Navarra (2011)
Effects of Tropical Cyclones on Ocean Heat Transport in a High Resolution Coupled General Circulation Model
J. of Clim. 2011 doi: [10.1175/2011JCLI4104.1](https://doi.org/10.1175/2011JCLI4104.1) in press.

Early online release: <http://journals.ametsoc.org/doi/pdf/10.1175/2011JCLI4104.1>

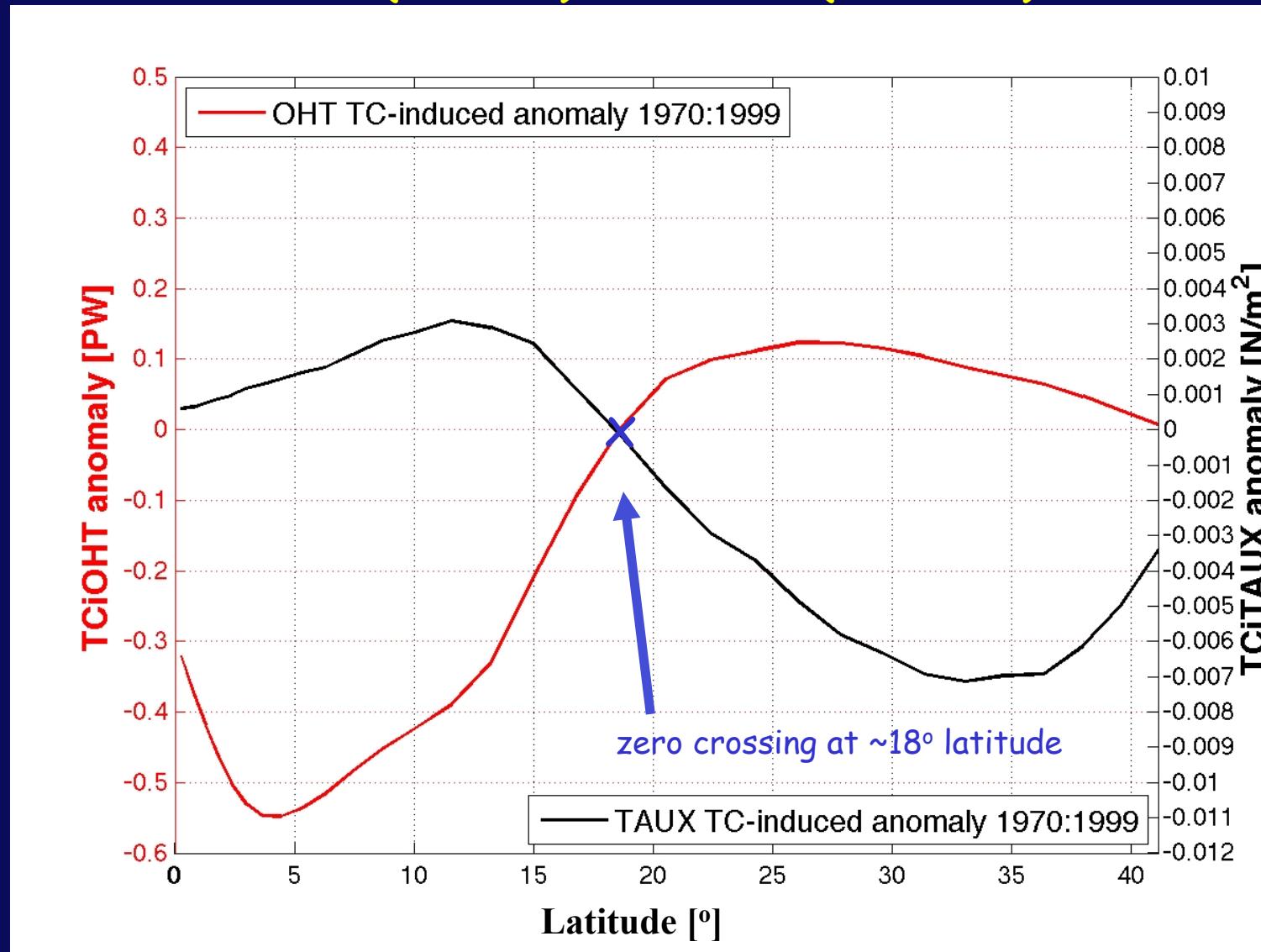
- Scoccimarro E., S. Gualdi, A. Navarra:

The Tropical Composite Cyclones: the integrated effect of hurricanes on the ocean-atmosphere coupled system.
Under submission.

scoccimarro@bo.ingv.it

How TCCs affect the Ocean Heat Transport

TC induced OHT (TCiOHT) and TAUX (TCiTAUX) Anomalies



How the model represent Tropical Cyclones

TCs detection method

A model tropical cyclone is active over a grid point "A" if the following conditions are satisfied following the TC-MIP CSIRO method (*)

1. in A $\xi > 1 \cdot 10^{-5} \text{ s}^{-1}$ at 850 hPa
2. relative minimum of SLP, and surface slp anomaly $> 2\text{hPa}$ in an area of 350Km around A
3. in a 350Km A surrounding area the surf. wind velocity $> 15.5 \text{ m/s}$ (**)
4. wind velocity (850 hPa) $>$ wind velocity (300 hPa)
5. Sum of T anomalies at 700, 500 and 300 hPa $> 1^\circ\text{C}$
6. The above conditions must persist at least 24 hours

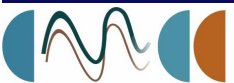
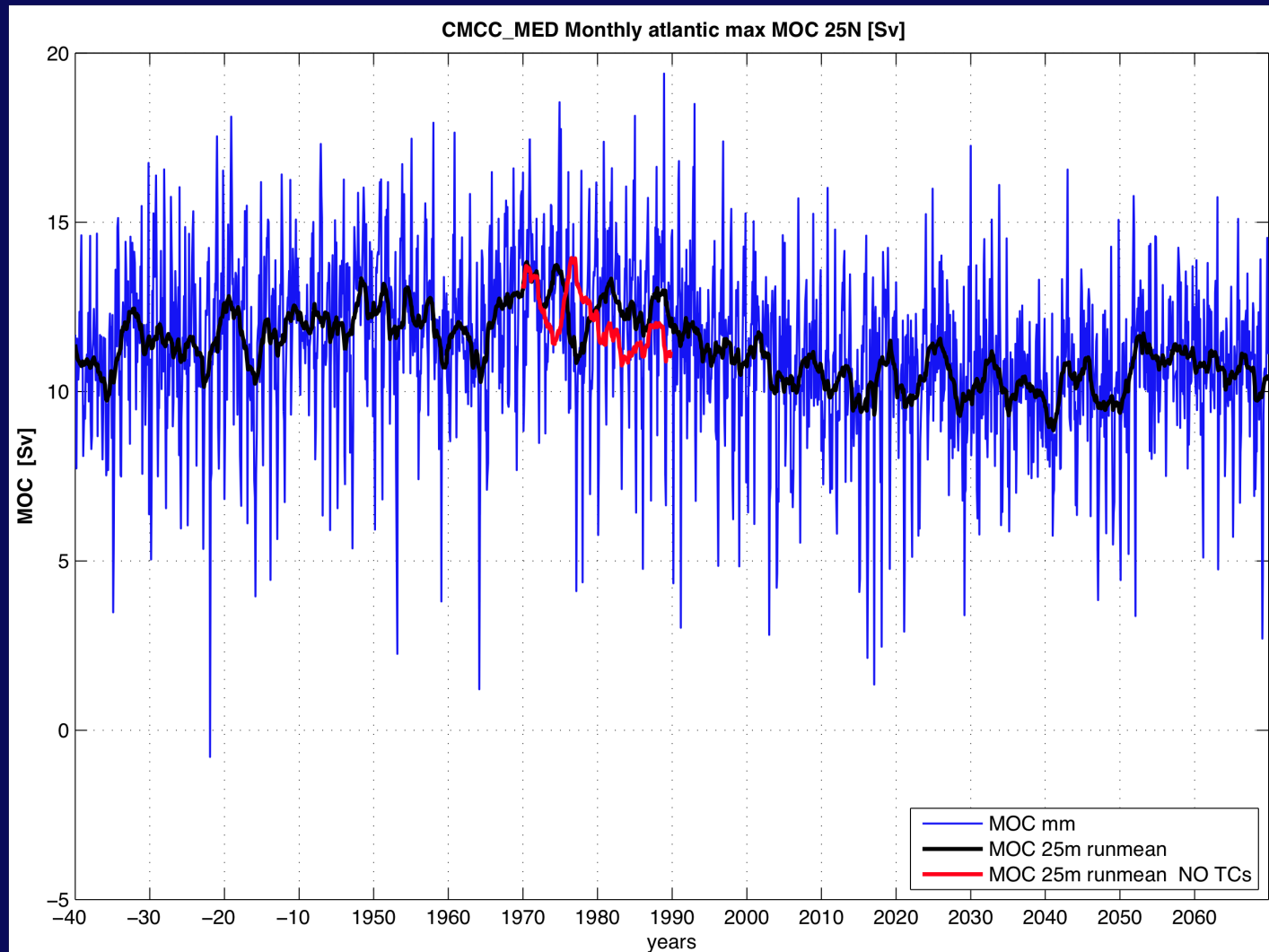
(*) [TC-MIP http://www.earthsci.unimelb.edu.au/~kwalsh/tcmip_index.html]

(**) [Walsh et al 2007]



TCs activity under the 21st century (A1B scenario)

ATL 25N MOC



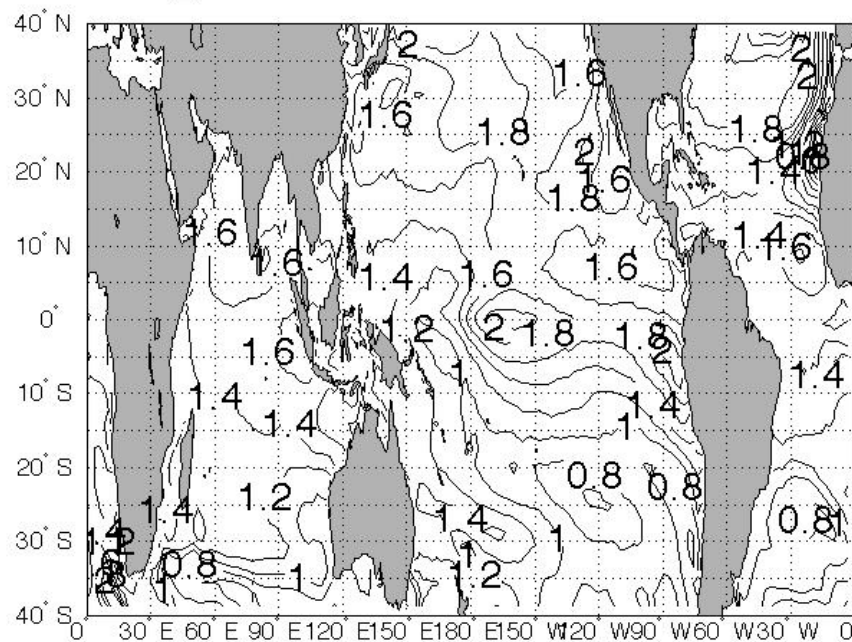
TCs activity under the 21st century (A1B scenario)

SST increase [°C] 2040:2069 - 1970:1999

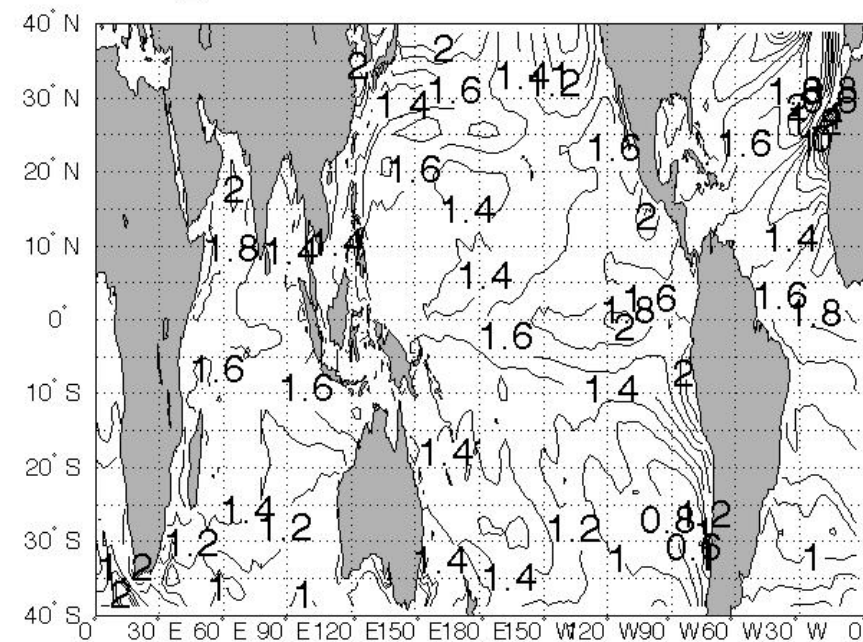
JJASO

DJFMA

CMCC_MED JJASO 2040:2069-1970:1999



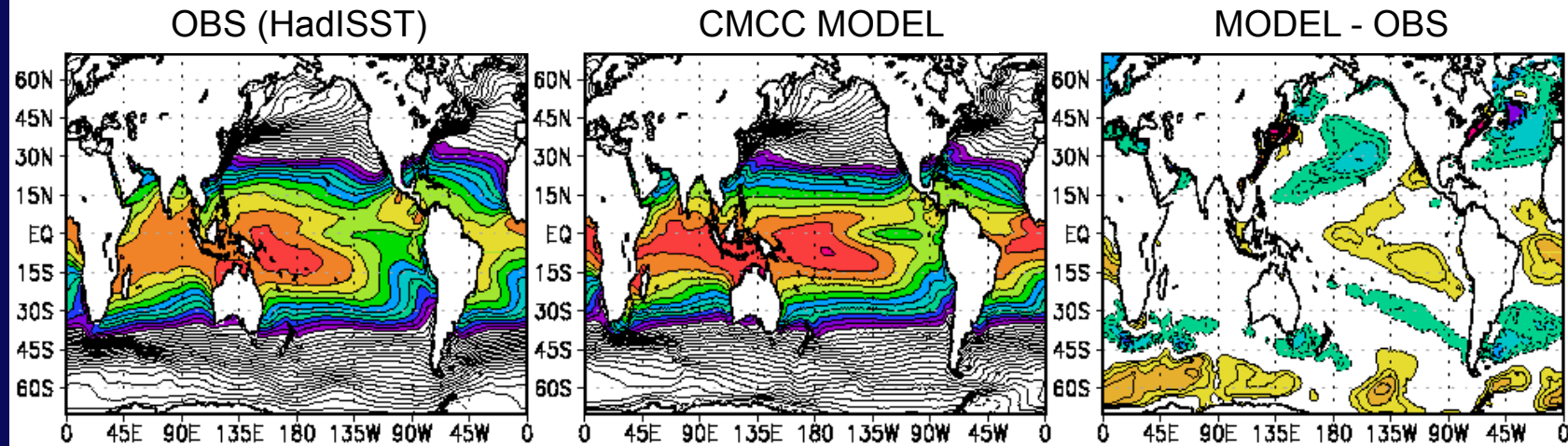
CMCC_MED DJFMA 2040:2069-1970:1999



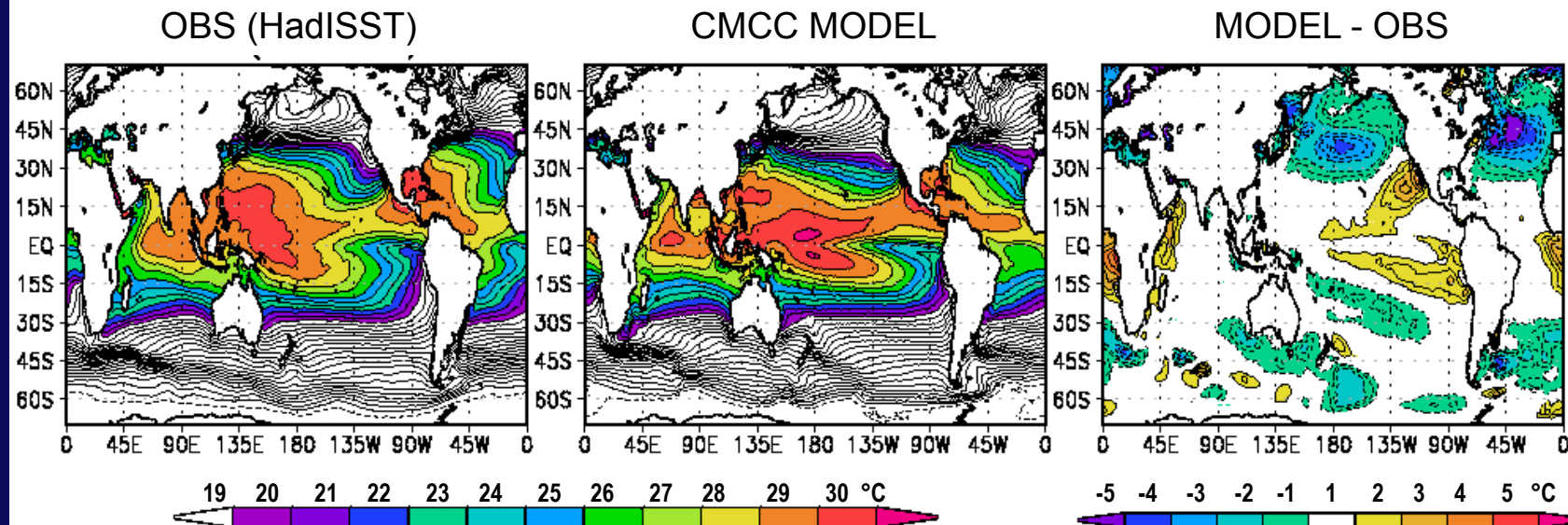
The CMCC climate simulation: present climate

Sea-Surface Temperature [°C] 1951-2000 mean

JFM

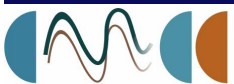
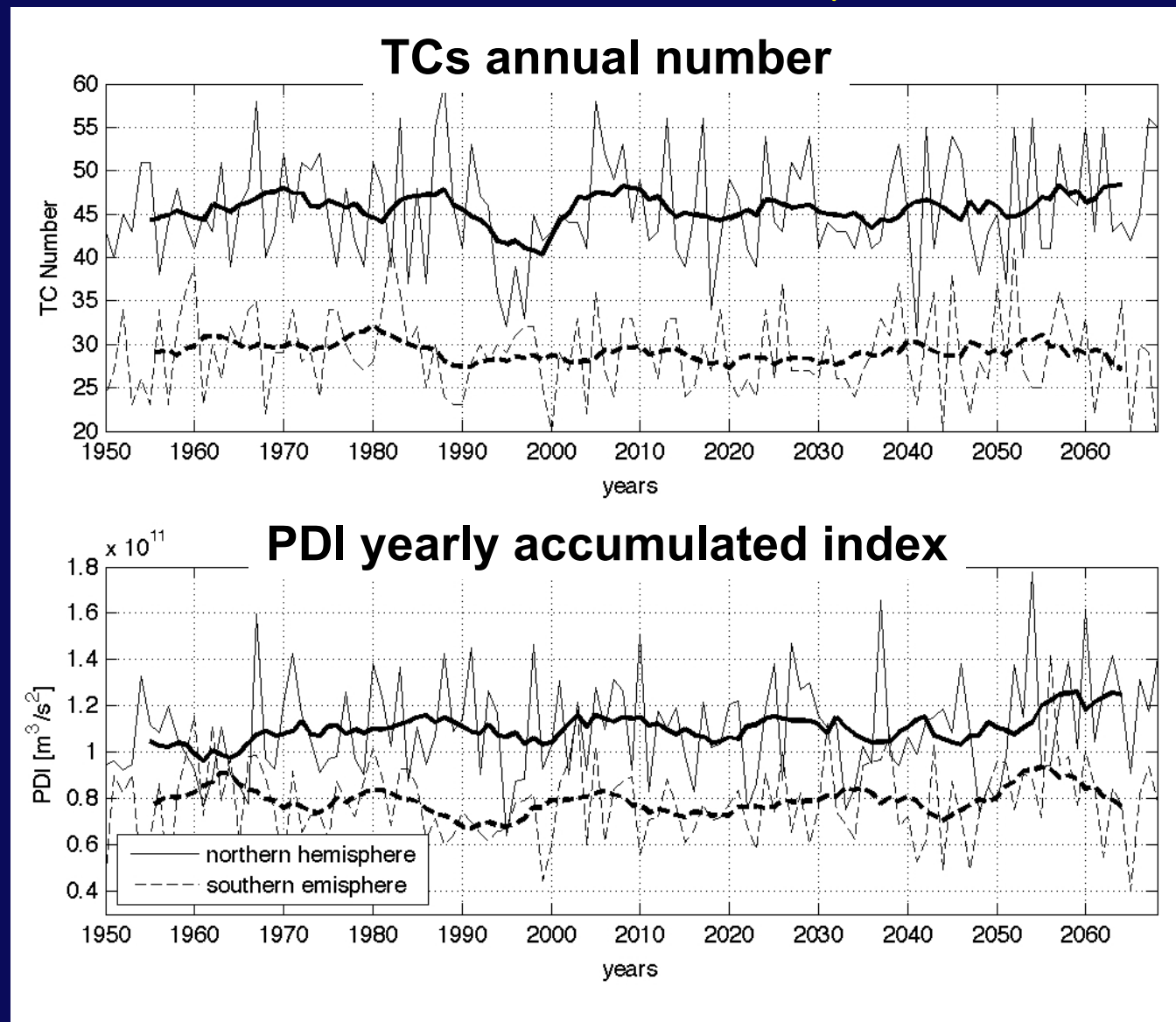


JAS



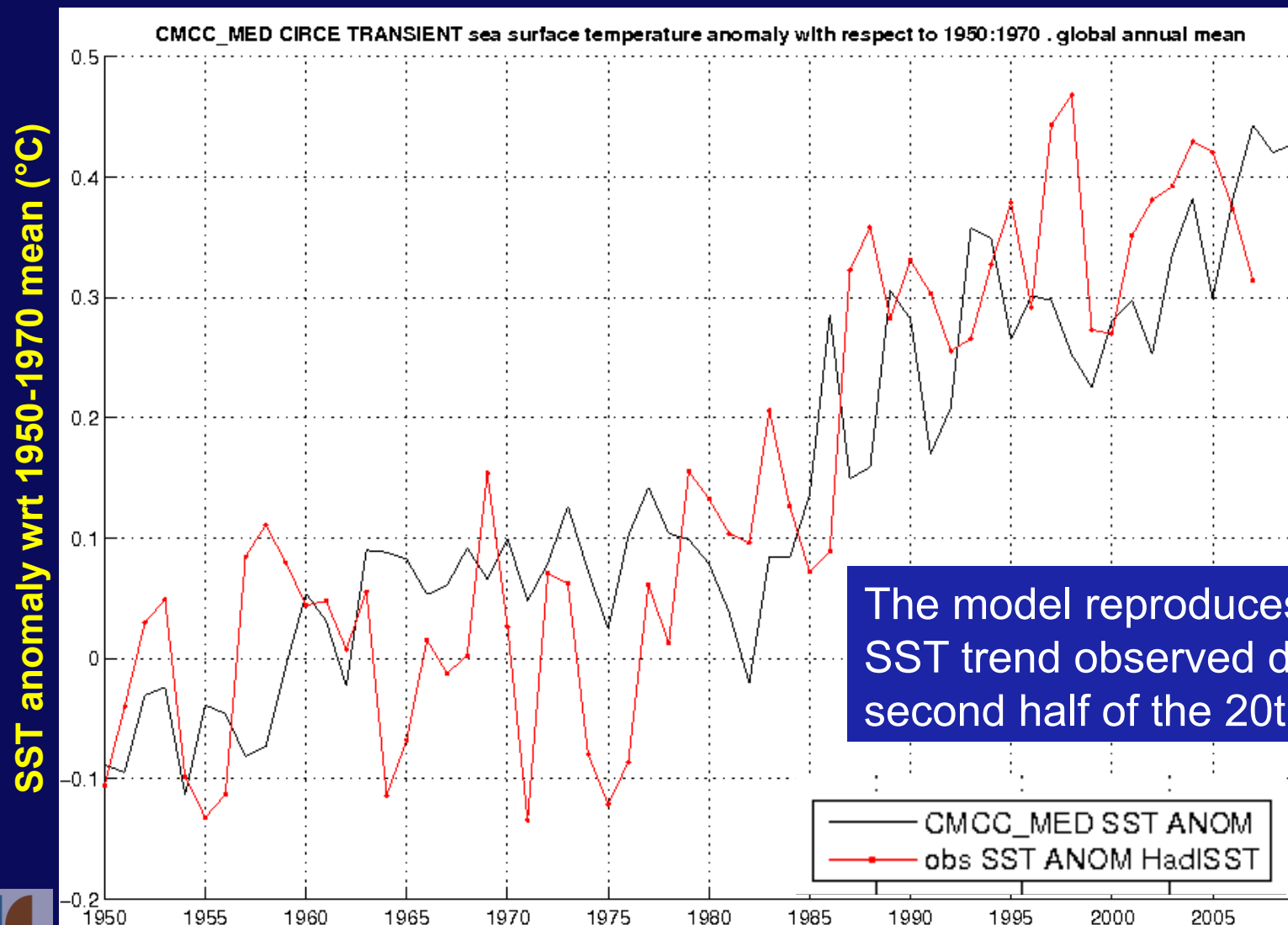
TCs activity under the 21st century (A1B scenario)

TCs number and Intensity (PDI)



The CMCC climate simulations: reproduction of the observed climate

Evolution of the global mean SST from 1951 to 2000:
observation vs. model



The model reproduces well the SST trend observed during the second half of the 20th Century

